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RUDIMENTARY TREATISE

ON

GEOLOGY.

BY MAJOR-GEN. PORTLOCK, R.E.,

F.R.S., F.G.S., M.R.I.A., ETC.

With Illustrations.

LONDON: JOHN WEALE.

Basaltic Slip—County of Derry.

The Ness Waterfall, County of Derry—in mica schist.

A

RUDIMENTARY TREATISE

ON

GEOLOGY:

FOR THE USE OF BEGINNERS.

BY

MAJOR-GENERAL PORTLOCK,

LL.D., F.R.S., F.G.S., M.R.I.A.,
&c., &c., &c.

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PREFACE TO SECOND EDITION.

An edition of more than 7000 copies having been sold of this little volume, I have endeavoured to introduce such improvements into this, the second edition, as are compatible with its form and object. In doing so, I have availed myself of some valuable suggestions of my friend Mr. Smith, of Jordan Hill, regretting at the same time that a limited space would not allow me to give a perfect analysis of his researches in Pleistocene and Post-Tertiary Deposits. If the labours of Travellers and Voyagers produce every year some new additions to our knowledge of the existing creation, can it be doubted that the Geologist, who is, as it were, a traveller in ancient worlds, must equally discover new and interesting facts? Geology is indeed a progressive science, which, although it has already produced much fruit, still continues to promise an abundant and never-failing harvest to those who diligently and skilfully cultivate it,—a truth which has been powerfully illustrated within the last few years, during which it has been shown that the highest type of organic beings, the mammalia, appeared on the earth so early as the Trias,—and still more recently whilst the last

sheets of this work were passing through the press, by the fact announced by Sir C. Lyell, that the foot-marks of a fresh-water tortoise had been discovered some years before in the *Silurian* strata of Canada, and by fresh examples of dicotyledonous plants in the Cretaceous strata,—thus unfolding most remarkable resemblances between the physical conditions of the earth at the most remote epochs and those it now exhibits. What an incentive then is held forth to the labourer in such a field, when to him may be allotted the triumph of penetrating still further into the mysteries of Nature, and discovering new relics of the animals and plants of extinct creations!

J. E. P.

Woolwich,
January, 1852.

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RUDIMENTARY GEOLOGY.

CHAPTER I.

Introduction.—*Experience* or *Practice* and *Theory* must be combined for the successful progress of all Science, and for the perfect development of Art.

As it is hoped that this little book may be read by many members of that valuable class of persons who are called practical men, it appears desirable to use it as an instrument for dispelling from their minds the prejudice they too often entertain against other men called scientific, and at the same time for supporting their own claim to the high estimation of men of science, which, as their most powerful auxiliaries, they so fully merit. The mutual distrust between scientific and practical men, though decreasing, does still exist, and is to be ascribed, as in most human differences, to the misapprehension or misinterpretation of a term, which term is in this case 'Science.' What then does the term Science actually signify? —simply knowledge: which may be viewed in two different lights, and be understood as implying either

A Knowledge of Facts, the result of observation; or

A Knowledge of Laws, obtained by reasoning on combined facts.

If these divisions be kept in view, it will be admitted that every human being must make more or less progress in the first branch of knowledge, as it is impossible to live and not to acquire some experience of facts; but that few, in comparison,

enter upon the second, which requires, in addition to observation, a power and a habit of reflection. And yet, however exalted this exercise of the higher quality of reasoning must intellectually be considered, it cannot dispense with that of observation, as every attempt at mere speculative reasoning has only led to mysticism, and retarded the progress of that real knowledge which proceeds either directly or indirectly from observed facts.

When the comparison of observed facts has led to the discovery of a law or rule according to which those facts are in connection one with the other, the mind acquires a power of extending or developing the law itself beyond the limits of the observed facts; and thus is enabled to advance into new regions of inquiry, and to foretell facts which have yet to be observed. And in like manner, the law or rule which has been ascertained to connect together one set of facts, may be found to agree with or even depend upon a law which connects together another set, the more compound law being thus traced up to the simple; and laws which from the different nature of the observed facts may have been deemed independent of each other, are brought into connection by being referred to some more simple law of which they are all proved to be developments.

Professor Lloyd ('Lectures on the Wave Theory of Light') has illustrated this subject. "You are aware," he says, "that in one mode of studying that interesting science, Astronomy, the laws of Kepler are assumed as fundamental principles, and from them, when unfolded, all the more obvious appearances of the planetary system are deduced. In Physical Astronomy, on the other hand, the laws of Kepler themselves are derived as *consequences of a primordial law of matter*, and the development of this higher principle has brought to light a multitude of other laws of the universe, which mere observation could have never reached." The name of Kepler suggests how instructive his example ought to be when as a practical man he is observed, submitting his pre-

judices to the test of experiment, and, by diligently following the movements of the planet Mars, and patiently comparing together its successive places, acquiring evidence that the orbit or curve in which it moved round the sun was not a circle but an ellipse, the sun being in one of its foci. This law of elliptic motion, and Kepler's two other laws, having been generalized and connected as necessary consequents with the elementary laws of matter, the range of observation was expanded over the whole material universe; and when, from the independent study of the motion of each planetary body, the Astronomer turned to the still more difficult investigation of the mutual action of one upon the other, and finally overcame and reduced to order all its difficulties, the Theoretic Astronomer was enabled, in the persons of Messrs. Adams and Le Verrier, to advance before the observer, and to direct him where to look for a remote and until then undiscovered planet, 'Neptune,' the existence of which they had inferred, by calculation, from its perturbating effects on other planets. To this noble result of patient practical observation, combined with and matured by study and reflection, M. Le Verrier has added another illustration of the aid derived by the practical observer from the labours of the theorist, by determining the elements of Faye's comet within definite limits, and thereby leading to its rediscovery by Professor Challis at Cambridge, on the 28th of November, 1850. This body, which had been seen before in 1843–4, is, from the passage of its orbit through that of the planet, subject to great perturbation from the planet Jupiter; and whilst M. Verrier, by calculating the amount of such perturbation, was enabled to trace the course of the comet through a disturbed orbit, he did not fail to perceive and to point out that the variation of the orbit itself will finally lead to a better appreciation of the disturbing force, or to a more correct determination of the mass of Jupiter: and similar illustrations might be multiplied from this one Science of the aid afforded to each other by the Observer and the Theorist.

Light, for example, is familiar to every one as a fact, however conflicting may be the modes of explaining the laws by which it acts. To our senses, as seen in the flash of a gun, it appears instantaneous, and yet it is progressive. This fact of the progressive movement of light was discovered practically by Roemer, when observing the eclipses of Jupiter's satellites, as he found that the mean time of the emersion of a satellite from the shadow of Jupiter's body was greater or less according as the distance of the earth was greater or less than its mean distance from Jupiter, such difference being due to the different times occupied by light in passing through the respective distances.

By a number of comparisons of the times of the emersions of Jupiter's satellites in the varying positions of the earth, it was ascertained that the reflected light occupied about 16′ 26″ in traversing the earth's orbit, and it may be stated in round numbers that the velocity of light is about equal to 200,000 miles per second, or more precisely 166,072 geographical miles, a velocity almost a million times greater than that of sound. Such a velocity seems beyond human comprehension; and yet the Astronomer, by pursuing the practical course of observation, has succeeded in measuring distances so vast that they permit the velocity of light to be used as an element in their expression. It is thus that the light of some of the fixed stars, whose distances have been determined, must have taken 3, 9¼, and 12 years to travel to the earth; or supposing the whole universe to have been contemporaneously created, 3, 9¼, and 12 years must have elapsed before those stars respectively could have been perceived on the earth; and were they now to be annihilated, the same periods must elapse before they will cease to be visible. There may indeed be heavenly bodies the light of which has not yet arrived at our terrestrial surface, and others may have been annihilated, although they yet appear to shine upon us; and we may therefore well say with Humboldt, that "whilst we penetrate with our large telescopes at once into space and time, and measure the one by the other, we may

receive the rays of light which come to us as if they were voices telling of the past; and however much we may diminish both the supposed distance whence the faint light of the nebulæ or the barely discernible glimmer of the remotest cluster of stars reaches us,—and the thousands of years which serve as the measure in time of that distance,—it will still remain true that, according to the knowledge which we possess of the velocity of light, it is more than probable that the light of the most distant cosmical bodies offers us the oldest sensible evidence of the existence of matter." And is not this a most important testimony for the Geologist; for when he too is obliged to speak of vast periods of time, may he not appeal to the Astronomer for proof, that the first act of creative power was exercised at an epoch so remote, that even the mighty velocity of light, and the vast distances of the celestial bodies, are inadequate as measures to express it?

The other phenomena of light, as its refraction, its double refraction, and its polarization,—those remarkable effects produced on light in its passage through crystalline bodies and by which their internal constitution may be examined,—might be also adduced as results of a happy union of the practical and theoretical, or, in other words, the observing and reasoning systems. It is indeed by a knowledge first acquired by induction from facts observed, and to the mechanical skill applied in aid of it, that the refracting telescope, and, by a similar knowledge of the laws of reflection of light, the reflecting telescope, have been so perfected as to open to our view an infinity of worlds and to track the very steps of their creation; whilst the achromatic microscope has been made to reveal to our gaze an infinity of minuteness equally wonderful, and to teach us the wonderful truth, that some of the solid rocks of our world are but an accumulation of countless myriads of minute organic bodies. Such intellectual triumphs as these demand on our part a tribute of admiration, not merely to the exalted genius which seizes on the laws which connect together great physical phenomena, but to the

practical man who, as a patient, careful, and acute observer, diligently watches for facts, or subsequently submits the theory established on them to the test of experiment.

Let us compare the ancient Mariner, cautiously pursuing his course along the shore and watching the declining star, with the skilful Voyager of the present time, who boldly quits the land, and securely steers over the expanse of ocean, the heavens affording him also a guiding light for his adventurous progress; and how great a difference will appear between the mere perception by the one of a regularity in the movements of the celestial bodies, and that accurate knowledge of the distances and motions of the various heavenly bodies which has enabled the Astronomer to supply the modern Sailor with tables and formulæ by which he determines from celestial observations his exact position and moves as securely upon ocean as upon land. And on the land itself, where the dense forest clothes the surface and forbids the ordinary operations of the Surveyor, recourse can be had to celestial observations, as was recently done in the determination of our North-Eastern American boundary by the Surveyors, Officers of the Corps of Royal Engineers, who having first determined the latitudes and longitudes of the ends of a line of 60 miles, deduced the azimuth or bearing of each end from the other, and then proceeded to cut down the trees according to these bearings, beginning simultaneously at each end, and so pursuing the respective lines through the forest until they both nearly met, the two parties emerging not indeed exactly opposite to, but in close proximity to, each other.

Astronomy, therefore, both in its marine and its terrestrial applications, affords the most powerful proofs of the advantage of never separating practice from theory; of considering the observer or the practical Astronomer as the fellow-labourer of the Theorist, and at the same time of frankly acknowledging the benefits derived from the profound investigations of the latter. M. Biot has stated his opinion that the only safe method of arriving at knowledge is by induc-

tion. "When observations have accumulated, they are compared together, and their errors discovered and eliminated. A correct knowledge is thus acquired of the state of the heavens, as to what is constant and what is variable, whether it be in a day, in a year, or in some still greater interval of time. The task of observing, or Practical Astronomy, ceases, and that of Theoretic Astronomy commences. Similar phenomena are compared together, in order to discover the laws by which they are linked together; and then again the inquiry is extended until the movements of the heavenly bodies have been shown to be in harmony with those mechanical forces and those laws of attraction which are found to operate upon all material bodies."

Chemistry is replete with illustrations of the principle which these remarks inculcate: it is an experimental science in the highest degree, and at every step of its progress appeals for information to the crucible and balance. And yet, though a practical science, it is rich in deductions of the highest philosophical interest which spring from the exercise of powerful reasoning upon carefully observed facts. Thousands had observed the phenomena of bodies falling to the ground before they suggested to the mind of a philosopher the laws of universal gravitation; and many a patient Chemist had weighed the resulting constituents of his careful analyses, ere the mind of Higgins obtained a glimpse, and that of Dalton a clear perception, of the remarkable law of definite proportions, by the discovery of which Chemistry was at once raised to the rank of an exact science. This law has now become so familiar that its beauty and grandeur are less considered than its convenience; although it may be doubted whether in the whole range of science any greater discovery was ever made than that which established the fact, that the combinations of material substances are neither arbitrary in kind nor quantity, but determined and limited by definite and invariable laws. The atomic theory of Dalton is a philosophic or theoretic expression of this fact; but whatever may be the fate of the

theory, the fact itself will remain incontrovertible: nor should its importance be lost sight of by the Naturalist, as he may deduce from the limitation of the powers of combining affinity an analogical reason for believing that organic species have been in like manner limited, and not left to the chances of progressive development. The progress made in Chemistry after the establishment of this leading law has been wonderful, and it may be said that the whole fabric of Organic Chemistry has been built upon it; whilst by the light it has thrown on the constitution of minerals, and on their variation within certain limits by a substitution of similarly constituted elements, one for the other, it has placed Mineralogy on a sound basis. Nor have the economic lessons of Chemistry been less important: in Agriculture, by showing the true constitution of various plants, they have established the value of inorganic as well as organic manures, and proved that the soil ceases to be productive from the exhaustion either of the mineral or the organic elements necessary for the growth of the plant; — they have shown also that the carbon of plants is principally obtained by the direct action of the leaves of the plant on the atmosphere;—they have discovered in vegetables many of the principles which were supposed to belong exclusively to animals, and pointed out a most singular analogy between the functions of both: "in plants," says Dumas, "the fruit, or rather the grain, is rich in fatty matter which is destined to produce heat by its combustion during germination; in animals the fat is also kept in reserve to be used for combustion in respiration, should the supply of nourishment fall short. There is reason to believe that the fatty matters originate in the leaves, and are thence carried to the embryo to be deposited either around it, or in the seed generally. These fatty matters pass into herbivorous animals, and from them into the carnivora, so that the supporter of combustion in the vegetable seed and in herbivorous and carnivorous animals has been elaborated in the green leaves of plants:" facts which may well excite the admiration of the

scientific and command the respect of the practical man; and it is by such lessons that the practical man is enabled to understand why he obtains successive crops of some plants from the same ground, as the Botanist finds a plant on the very spot where it has flourished for ages, although his corn crops, by taking away from the ground the necessary inorganic elements, quickly render it unfitted for their continued growth. Chemistry goes hand-in-hand with Geology in this important practical application, and the Farmer is beginning to cast off his ancient prejudice, and to hail, as most useful auxiliaries, sciences which not merely indicate to him the valuable qualities of the various mineral substances which enter into the vegetable structure, but even direct him where they are to be found.

The practical man is however aware that in any occupation of life no theory can supply the place of practical skill; and the consciousness of the necessity of such skill too often induces him to overlook the fact, that skill was originally set in motion by science, and that what is sometimes called a lost art, ought in reality to be styled a lost science. It is thus that many processes of a very ordinary character, such as those so long adopted in the manufacture of white lead, a pigment known to the Ancients, involve principles of high scientific interest, which must have been perceived, however obscurely, by their first originators.

The beauty and excellence of church glass during the mediæval ages were probably the consequence of scientific knowledge in some of those early students of Nature, the Monks; and if the art is now reviving, and promises ere long to rival its former condition, the improvement should be ascribed to science applied in aid of practical skill. Such examples might be multiplied from the processes of bleaching, dyeing, distilling, and of Metallurgy; and even more strikingly from the application of electric and electro-magnetic science to the galvano-plastic processes and to the telegraph; all tending to demonstrate that whilst the only sure basis on which any

science can be founded is the observation of facts, or, in other words, practical inquiry, so also the sure basis of every art is science. When, however, an art has been founded on a sound knowledge of principles or laws, practical skill may, by the tact it acquires, greatly improve and advance it, and an art may be even perpetuated in the hands of those who have forgotten, or perhaps have never known the science on which it depends; and it is thus that, in some refined art which has come down to us from a remote epoch, we may often read a record of scientific labours which have left no other trace behind them.

The characteristic of the present age is the continued effort to trace every practical result up to a scientific principle, and to seek in that knowledge of principles a power to modify or extend results. The truly wonderful development of all branches of our manufactures; the extending application of machinery in aid of human labour of every description; the state of our communications by sea and land under the impulse of steam power; the application of magnetical and electrical science to so many practical objects; each, and all of these, testify to this one great axiom, that permanent improvement can be founded on knowledge only. Before the light of science secrets disappear or become principles. It is thus that the French Chemists, MM. Ebelmen and Salvetat, have devoted themselves to an inquiry into the composition of the materials used by the Chinese in the fabrication and decoration of porcelain, and having completed their chemical analysis, have already commenced experiments at Sévres, in order to reproduce in that manufacture the colours of the Chinese artists. But there is perhaps no more striking example of the power of science to dispel mystery than is to be found in the researches of M. Boutigny D'Evreux. That ingenious philosopher has ascertained that the old miracles of the ancient priests of Zoroaster, and the equally wonderful examples of the successful issue of the ordeal by fire in the mediæval ages, are explicable on sound physical principles, and has tested the accuracy of his reasoning by plunging

without injury his hand into baths of molten metals. This remarkable phenomenon he explains by assuming a new force, namely, the repulsive power of caloric at sensible distances acting on liquids in what he calls the spheroidal state; but to the explanation strong objections have been urged, and M. Person considers it unnecessary to seek any new cause, and ascribes the result to the tension of a film of vapour which is suddenly formed between the heating body and the liquid and keeps them separate. If, for example, the hand be either naturally or artificially moist, there will be produced on its approach to the melted metal a film of vapour which will, by its tension, repel the metal from the hand, and for a time preserve it from injury; or if the hand be dipped into ether, and then into boiling water, there will be a coating of vapour of ether formed on the hand, which will repel the boiling water and preserve the hand from scalding. In all these cases only part of the protecting fluid is reduced to vapour, and there is between the vapour and the hand a coating of the fluid, which being a bad conductor of heat, further insures safety; the only precaution necessary being that of selecting for the protecting fluid one in which the vaporizing temperature is considerably below that of the melted metal or of the boiling water.

In no science has the value of inductive reasoning been more strikingly illustrated than in Geology, which is the more immediate object of this volume; nor has any more strongly proved the importance of the sound knowledge thus acquired in advancing the practical interests of mankind. Glimpses of the formative and modifying functions exercised by both fire and water were assuredly obtained by the Ancients; for it was impossible that thinking men could contemplate the action of rivers and of the sea in wearing, transporting, and depositing the mineral matter of the earth's surface, or that they could watch the glowing flood of melted lava, as it poured from the volcanic crater, without recognizing the power of those great agencies. To them, however, the labour of collecting facts was distasteful, and the passion of specula-

tive theorizing was so strong, that whilst they played with the dreamy hypotheses of possibilities, by turns advancing to or receding from the truth and sometimes even anticipating discovery by conjecture, they never succeeded in establishing a correct theory of the formation of the earth. So long indeed did this spirit of speculation continue to maintain its influence, that the Baconian system of inductive reasoning only slowly made its way in Geology; and the positive evidence of the senses was rejected in the case of fossil organic bodies, or the remains of ancient and no longer existing animals found imbedded in the stony masses of the earth's strata, and it was attempted to explain their existence by a hypothetic plastic power in Nature which had been exercised in forming so many *lusus naturæ*. It would be useless to euumerate all the great men who have aided in dispelling the obscurity consequent on mere scholastic discussion by appealing to an observation of facts. In doing so they pursued two leading courses: the one, an examination of the mineral matter of the earth's surface, with a view to determine the actual manner in which it had been arranged; the other, an investigation of the nature and history of those vestiges of animals and vegetables, which, being found in the interior of mineral masses, prove that a portion, at least, of the crust of the globe has been formed subsequently to the existence of organic beings. Lehmann, in 1756, made the first satisfactory step towards a correct knowledge in the mineral inquiry, by his description of the stratified deposits (Flætzgebirge) of the centre of Germany. Subsequent Geologists pursued the same course of careful observation, amongst whom may be specially noted the illustrious Saussure; and at the close of the last century, Werner gave new impetus to the science by generalizing the results of his own observations, and arranging them into a system. It was to be expected that the peculiar district or field of inquiry would influence materially the deductions of the first observers; and that whilst Werner built up an aqueous theory, in which he supposed all mineral

matter to be deposited from a solvent fluid, Hall, having derived his knowledge of the action of highly heated masses from the examination of a totally different country, established an igneous theory; and that modern Geologists, proceeding on the principles so ably set forth by Sir Charles Lyell, who may be considered the founder of our present system of geological reasoning, would hesitate to reject any cause which can be now observed in the operations of Nature, and would carefully combine together in one great system all those forces which, whether aqueous, aerial, or igneous, now act on the earth's surface, and judging from the similarity of effects so palpable in the ancient strata, have also acted at all former periods within the reach of our observation. In the second branch of inquiry the progress was even slower; for though, in 1517, Frascatoro had remarked that all the organic fossils then discovered could not have been buried at the same epoch, and Stenon, in 1669, had hinted that they might be used to distinguish the relative ages of the masses containing them, the prejudice to be overcome was so strong, that Palæontology can scarcely be said to have become a recognized branch of geological science until William Smith announced, in 1790, the design of publishing a geological map of Great Britain, which he effected in 1815, and thus promulgated the fact, that England is constituted of strata the superposition of which is constant and never inverted, and that the same fossils being found in all parts of the same bed, it may be characterized by those fossils. The genius of Cuvier shed a new and brilliant light over Palæontology by establishing the laws of anatomical composition, and building up in conformity with them the remains of the higher animals, so as to exhibit to the Naturalist many remarkable forms which, though they have ceased to exist, are connecting links in the great chain of the animal kingdom. Many are the great men who have continued to work out, with unceasing labour, this great subject; and it is no small gratification to know that Greenough, Buckland, Sir H. De la Beche, Lyell,

Sedgewick, Conybeare, Fitton, Phillips, Murchison, are still living amongst us, and by their inquiries and their reasonings, adding new lustre to a science which has, as it were, grown up under their care and guidance. Geology, therefore, is now a true science, being founded on facts and reduced to the dominion of definite laws, and in consequence has become a sure guide to the practical man: the Miner finds in it a torch to guide him, in his subterranean passage, to the stratum where he may expect to find coal or iron, or to the recovery of the mineral vein which he has suddenly lost;—the Engineer is guided by it in tracing out his roads or canals, as it tells him at once the firmest stratum for supporting the one, and the easiest to cut through for the other, and makes him acquainted with the qualities of the materials he should use in his constructions, and the localities where he should seek them;—the Geographer finds his inquiries facilitated by learning from Geology the influence of the mineral masses on the form and magnitude of the mountains and valleys, and on the course of rivers;—the Agriculturist is taught the influence of the mineral strata on vegetable and animal life, and the Statesman discovers in the effects of that influence a force which stimulates or retards population;—the Soldier also may find in Geology a most valuable guide in tracing his lines both of attack and defence;—and it is thus that a science rich in the highest objects of philosophical research is at the same time capable of the widest and most practical application.

Can it be doubted, then, that there ought to be an intimate union between practical and theoretic men,—between the observer and the philosopher?—and is it not also evident that the position of the practical man is often most favourable for the collection of facts which he overlooks only because his mind has not been trained to observe? When the most simple practical man has observed a fact, to that extent, he has acquired knowledge and become scientific; and though he overlooks many other facts, he has often stored up more knowledge than is supposed by the theorist. To extend his powers of

observation is the object of this volume, and it is believed that every applied science will acquire additional extension and stability by availing itself of the quiet labours and sound sense of practical men.

CHAPTER II.

Geology—Its Meaning, Object, and Utility as a Science.

Geology, a treatise or discourse on the Earth, is a term which admits of a very wide interpretation, and naturally suggests to the mind inquiries—1st, into the formation and original condition of the earth; 2ndly, into the successive modifications which it has undergone, and the agencies by which they have been effected; and 3rdly, into its present condition, and the agencies which are still producing changes in that condition. The first object, then, of the Geologist is to establish, on the principles of inductive reasoning set forth in the introductory chapter, the science as it depends on each of these inquiries, and then to apply it to the practical purposes of life: and it may be premised that a science is practically valuable just in proportion as its facts have been discovered, and its laws established and studied, for so long as we are uncertain whether a known result has proceeded from a definite cause, we are unable to apply the fact or circumstance to the elucidation of other facts or circumstances, and so long as we are unacquainted with the properties of any substance under our examination, we cannot declare with certainty what share it may have had in the phenomena we have observed. This may be illustrated by a reference to gunpowder: its explosive quality is the result of its composition, and we can only depend upon the results when we know that the compound has been accurately formed: to insure, therefore, certainty in the operations depending on it, we must take care that a proper standard of composition has been adhered to. In a similar manner, we can only apply Geology as a practical

science when we have ascertained and made ourselves familiar with those facts which prove the first principles on which it has been founded to be correct and stable.

To obtain any idea of the earth's formation and original condition, we must treat Geology as a branch of the physical sciences. The earth, as one of the planetary bodies revolving round the centre of our solar system, must, like all the other planets, be subject to the great laws by which they are at once retained in their orbits and caused to revolve on their axes; it is only one member of a great whole, and in its density, its volume, and its mass, is in strict relation to all the other bodies of the same system. The first formation, therefore, of the earth, or the manner in which it was probably condensed from nebulous matter, and reduced to the planetary form, may be considered a portion of Astronomical science.

It is thus that Astronomy has assisted in the determination of the form of the earth, and it is now known to be an oblate spheroid, of which the equatorial diameter exceeds the polar by 139,296 feet, or about 23 geographical miles,—a difference equal to more than nine times the height of Mont Blanc, or five times the height of the highest point of the Himalaya chain. And in like manner, by referring to the laws of matter as exhibited in gravitation and attraction, the Philosopher has been enabled to weigh the earth he had before measured, and has determined its mean density to be about 5½ times that of distilled water: but as the actual mean density of the solid matter of the earth's surface, its rocks and strata, does not exceed 2·9, there must be an increase of density from the surface to the centre of the earth. It is impossible that man should descend so low into the interior of the earth as to discover from within the actual condition and nature of its mineral masses, but he has, at least, obtained from without some clue to it in the falling aerolite, or meteoric stone,—the elementary identity of which with the matter of our earth,—the presence amongst its constituents of the mineral augite, which is an essential ingredient of sub-

aqueous volcanic products,—the unoxydized condition of its iron, which indicates that it had not been exposed to atmospheric agency, and its high specific gravity 3·575, that of the iron itself being 7·715,—are illustrations of the internal constitution of our own planet, and of a general harmony in its mineral matter and that of the other planetary bodies. In other stages of the subject there will be frequently occasion to refer to general physical laws; but if we turn for the present to the more practical investigation of the past and present state of the earth's surface, we shall soon be convinced that there is something more in its rocks and strata than mere masses of stone, or heaps of gravel, sand, and mud, confusedly thrown together: we shall find, in fact, that these deposits have been the result of forces tending, according to the ordinary laws of nature, either to break up and remove, or to deposit and consolidate in new forms the mineral strata, and that Geology is thus connected with the experimental sciences of Meteorology and Chemistry: nor is this all; for whilst we examine the mud and sands of our own coasts and seas, and find either imbedded in, or resting upon them, the relics of many living species of animals and plants, we cannot overlook the analogy in distribution and arrangement exhibited by the sandstones and clays of other epochs, and the wonderful fact that they too are associated with the relics of organic beings: we learn indeed the close connection of Geology with all the natural sciences, and are taught to view it not merely as an humble investigation of the circumstances of inert matter, but as a lofty exposition of the mysteries of organic creation.

Enough has been said to impress upon the reader the philosophical importance and dignity of Geology; and it can be easily shown that its practical importance is the result of its philosophical connection with the exact sciences. For example, were all the deposits we meet with, here rock and there sand, gravel, and clay, mere arbitrary heaps which had never been brought under the controlling influences of organic

or inorganic forces, we should be unable to use the one as an index to the history of the other, and the study of each individual deposit would end as it had begun, in itself alone. But if it be proved that certain physical agencies have, according to fixed laws, been in operation from the earliest periods of our planet's history, and that they have either co-operated with, or acted upon, organic beings, so as to check, modify, or destroy, at successive epochs, animal and vegetable life,—and if in the strata themselves we can find the fossilized relics of successive races of organized beings, and can make the one a guide to the other,—how different is the result, uncertainty now giving place to certainty, and a knowledge of the strata of one portion of the earth's crust becoming a clue to the investigation of the strata of any other. It is upon this certainty, obtained by the collection and collocation of facts from all parts of the world, that Geology rests its claim on the attention of practical men.

In order to acquire a clear conception of geological phenomena, it is necessary to take a brief review—1st, of the various elementary substances which enter largely into the composition of the earth's crust, and of the fluids connected with it; and 2ndly, of the principal compounds formed by them.

Including most of the metals, there are more than fifty substances which, having hitherto resisted the efforts of the Chemist, are still considered simple. Of these, sixteen only occur extensively amongst ordinary mineral compounds, whether fluid or solid: they are, *oxygen, hydrogen, azote* or *nitrogen, carbon, sulphur, chlorine, fluorine, phosphorus, silicium, aluminium, potassium, sodium, magnesium, calcium, iron,* and *manganese,* which, combined together in various ways, compose the greater portion of the earth's crust and of its seas and atmosphere. Some of the other elementary substances, as bromine, iodine, and borine, are highly interesting, and some, as the metals, are most important; and though they do not constitute so large a portion of the whole as to require a

specific notice in this part of our subject, the remarkable extension of some of them throughout nature deserves remark, as is especially the case with iodine, which will be therefore included in the list of Geological elements.

The important offices of some of these substances are generally known; as for example, of hydrogen and oxygen in water,—of oxygen and nitrogen in air,—of carbon as a minute but very essential constituent of air,—of carbon again as a combustible substance in turf, wood, and coal,—of iron as the most useful of metals; but in addition to these well-known offices, they have others, which are little less essential and marked, to perform in the mineral constitution of the earth's crust, the minerals of which it consists being principally formed by the combination of some of these elements with the principal metallic bases; a fact which will become evident as we consider them in order.

Oxygen combines with silicium to form silica, of which it constitutes more than a half; but silica, either pure, or combined as an acid with metallic bases, has been estimated to form almost one-half of the solid crust of the terrestrial globe; and hence oxygen, in this one condition, is equivalent to a quarter of the ponderable matter of the earth's surface. But oxygen is also combined with aluminium to form alumina, an earth which is an essential constituent of certain minerals and rocks, as mica and clay slates, &c., which extend over large tracts of the earth's surface and produce by their decomposition the beds of clay, so general throughout the world,—the several varieties of clay being essentially silicates of alumina proceeding from the decomposition of the felspar and mica of granite, gneiss, mica slate, and clay slate,—and when the quantity of mud or clay found in modern alluvium and the beds of clay in more ancient deposits are considered, the importance of alumina is only second to that of silica; but of this earth, oxygen in weight forms nearly one-half. Again, oxygen forms nearly one-half of carbonate of lime, the basis of limestone, a mineral of which, in many parts of the world,

mountain masses of many hundreds of feet thickness are constituted. And if we add to these instances its presence in water, which is so abundant in the mineral as well as the vegetable and animal kingdoms, and of which it forms in weight eight-ninths, we may readily believe that of the whole crust of the earth, at least one-half is composed of this remarkable element.

Hydrogen, as a constituent of water, enters into the composition of many minerals and mineral strata, and forms a part of almost every organic substance.

Azote or *nitrogen,* as a constituent of the atmosphere, of most animal and of several vegetable substances, is an important element, although it is scarcely appreciable in the mineral kingdom. Traces of this fundamental element of animal organization are, however, to be observed, in the form of ammonia which is a compound of nitrogen and hydrogen, in strata which contain the fossilized remains of animals, and such traces have been appealed to as a test of the former presence of animals in strata which now exhibit no fossil evidence of their existence; but however striking this exhibition of ammonia may be, it is subject to so many sources of uncertainty as to be justly considered insufficient in deciding so obscure and difficult a question. One of its compounds, nitre or saltpetre, nitrate of potash, is well known as a constituent of gunpowder: it is produced naturally and is found efflorescing on old walls. In India it is so abundant as to crystallize on the surface of the soil. The analogous salt, nitrate of soda, occurs in Peru in a bed several feet thick, and extending over a space of more than 40 leagues.

Carbon, the basis of coal, the base of carbonic acid, and the most considerable element of the solid parts of animals and vegetables, is one of the most important substances in nature; it forms nearly one-eighth part of carbonate of lime, and is therefore an essential constituent of the earth's crust. In its purest form it constitutes the diamond, at once the hardest and most brilliant of gems.

Sulphur, a constituent of animal and vegetable substances, is exhaled in large quantities from many volcanoes, either in a pure state or in combination with hydrogen, and has probably proceeded from some of the mineral substances with which they are connected or has been sublimed from deeply seated beds of sulphur by volcanic heat. It is also a part of the mineral crust of the earth, as it occurs in the sulphurets of the metals, and in sulphate of lime or gypsum. As regards the sulphurets, its presence is sometimes secondary, being the result of the partial decomposition of the sulphuric acid of soluble sulphates in a singular chain of compositions and decompositions. In beds of shale, iron pyrites (bisulphuret of iron) is frequently very abundant, and when water gains access to it, there is a partial decomposition, some of the oxygen of the water combining with the sulphur to form sulphuric acid, which then combines with the iron, also oxydized from the water, to form sulphate of iron. The soluble sulphate is carried away by the filtering water, and when it comes in contact with animal or vegetable substances imbedded in the strata, is again decomposed, the oxygen combining with the hydrogen and carbon of the organic bodies to form water, carbonic acid, and carburetted hydrogen, and a sulphuret of iron being deposited in their tissues. The results of this process, as exhibited in fossil vegetables and in the organic portions of shells and fish, are sometimes very beautiful, and it may be conjectured that this succession of compositions and decompositions will yet be traced up to an earlier commencement in the more ancient geological strata.

M. Ch. Blondeau has recently discovered that sulphuret of arsenic exists, in solution, in all powerful mineral springs or waters, and he ascribes their medicinal effects to its presence. Sulphurets of iron and of manganese are also found in thermal waters.

Chlorine, as a constituent of chloride of sodium (common salt), takes part in the formation of those extensive beds of rock salt which occur in various geological formations. Chlo-

rine forms nearly $\frac{7}{12}$ths of chloride of sodium, and is therefore another example of a gaseous body entering extensively into the composition of the earth's crust. United with hydrogen as hydro-chloric acid, it is evolved from volcanoes.

Fluorine, when combined with oxygen as fluoric acid, unites with lime to form fluate of lime, or fluor spar, which is often associated with lead in vein-stones. It is also a constituent of mica and hornblende, but it may be considered important rather in a mineralogical than geological sense.

Iodine is well known as a powerful medicinal agent. Combined with the bases of potash, soda, and magnesia, it co-exists with common salt in sea-water and in marine plants. It has also been recently proved by M. Chatin that it exists in fresh-water plants, in the waters of rivers, springs, and wells, and in the structure of aquatic animals, so that it is evident that this substance, only discovered in 1811, is widely spread over the surface of the earth, and doubtless forms a part of its internal mass. It has also been found in coal; and M. Chatin has deduced from the greater or less amount in the several varieties of coal, Anthracite and Lignite, an argument for ascribing their origin either entirely to cryptogamic aqueous plants, to a combination of aqueous and terrestrial, or chiefly to terrestrial plants, as the particular case may be. Iodine has been found combined with silver as an iodide of silver in Mexico.

Bromine also occurs in sea-water combined with the base of magnesia, and has also been found in salt springs.

Borine combines with oxygen to form boracic acid; and the salt borax or borate of soda is formed naturally on the soil in Thibet, and is found also at the bottom of certain lakes. Boracic acid occurs in the crater of Volcano, one of the Lipari Islands, and is emitted from the earth in combination with hot vapours in Tuscany: it is a constituent of the mineral tourmaline, which contains about 8 per cent. of boracic acid, and the wide distribution of that mineral, estimated by number of localities and not by quantity, combined with the volcanic

origin of the acid, proves that borine must have formed part of the original mass of the earth.

Phosphorus.—A constituent of phosphate of lime, which is, as Apatite, rather rare in the mineral kingdom, but is a most important compound in the animal kingdom, being the mineral portion of bone, the strength and stability of which depend upon it. It is also a constituent of many vegetables, and *enters from them into the animal structure.* Darwin mentions two curious secondary productions of phosphate of lime,—one at St. Paul's Islands, where the rocks are coated with it, the action of the spray on the dung of sea-fowl having produced phosphoric acid; and at Ascension, where stalactites of the same mineral have been produoed in a similar way.

Silicium or *Silicon,* the metallic basis of silica.—The important position this substance occupies has been shown under 'Oxygen;' most of the minerals, exclusive of the carbonates and sulphates of lime which form the earth's crust, appearing in the form either of silex or of silicates. The water of springs and wells always contains a little soluble silica: in mineral waters its quantity is sometimes more considerable, and associated with an alkaline carbonate, it occurs in the hot alkaline spring of Reikum, in Iceland, and in the boiling jets of the Geyser. These latter modes of occurrence indicate the slow but continued destruction of the silicates of the mineral kingdom, and afford a probable explanation of the formation of much of the crystalline quartz in nature: on the solution of many limestones gelatinous silica is found, and its presence indicates that a similar process was connected with their formation.

Aluminium, the metallic base of the earth alumina.—Alumina, as one of the principal constituents of clay, and of all those minerals and rocks from the decomposition of which it is produced, is, as shown under 'Oxygen,' a most important portion of the earth's crust. It is also well known as one of the component parts of alum, a salt extensively used in dyeing,

which is a double sulphate of potash and alumina. The sulphate of alumina is formed naturally by the action of sulphuric acid, proceeding, as already stated, from the decomposition of iron pyrites, on the beds of clay or of shale in which that mineral is abundant. The sulphate of alumina being dissolved out, and separated by crystallization from the proto-sulphate of iron formed at the same time, is mixed with sulphate of potash, and the two combine to form the double salt alum. Alum-stone, a natural product of volcanic countries, also yields, by heating, this substance: it is abundant in the ancient crater of Solfatara, near Naples. Though alumina is the principal ingredient of plastic clays, it forms nearly 99 parts out of 100 of the beautiful gem sapphire, next to the diamond in hardness.

Potassium, the metallic base of the alkali potash.—Potash is a component of many minerals, especially of felspar (a well-known constituent of granite and gneiss), of which, in the condition of a silicate, it forms nearly $\frac{1}{6}$th part. The soil is provided with the potash necessary for the support of various plants from the decomposition of rocks containing felspar; and being again extracted from these plants to be used in the arts, it has obtained the name of vegetable alkali. It is the base of the important mineral compound, nitre or nitrate of potash.

Sodium, the metallic base of soda, an alkali which replaces potash in albite (soda felspar).—Soda has been called the mineral alkali, in contradistinction to potash; but such distinction is without foundation, as carbonate of soda is obtained from kelp, or the ashes of calcined sea-weeds, and might therefore, as a secondary product, be also called vegetable. Soda is likewise found in all animal fluids, and the base itself is widely diffused in that most valuable salt, the chloride of sodium, or common salt. The importance of sodium as one of the constituents of the mass of the earth will be understood better by estimating the quantity of salt in sea-water than that in beds of rock salt, however extensive. Chloride

of sodium forms about the $\frac{1}{40}$th part by weight, or about $\frac{1}{88}$th part by bulk, of sea water, and the bulk of the sea being about $\frac{1}{578}$th of that of the whole earth, the quantity of salt it contains is about $\frac{1}{50864}$th part of the whole earth, or about $\frac{1}{16}$th part of the bulk of the actually protruding or dry land. If it be considered probable that the saline condition of the sea is only the result of the long-continued action of water upon the solid mass of the earth, there will appear to be good reason for assuming with some philosophers that sodium, potassium, and other metallic bases were important original constituents of the nucleus of the earth, and that by their sudden combination with chlorine and other gases they produced some at least of the convulsive disturbances of its crust. Nitrate of soda abounds in Peru.

Magnesium, the metallic base of the earth magnesia.—Magnesia, as a silicate, is a component of many important minerals, especially of pyroxene or augite, of amphibole or hornblende, of steatite, and of serpentine. Of hornblende it forms $\frac{1}{5}$th part. It is also remarkable as a constituent of dolomite, or magnesian limestone, a combination of the carbonates of lime and magnesia which is very extensively diffused in nature, and forms occasionally mountain masses. The effect of magnesia on vegetation is well known. As a carbonate, it would in itself perhaps be innocuous, but as it forms on decomposition very soluble salts, it may be carried into the vegetable organism, and thereby prove injurious. As an alkaline earth it is dangerous from continuing so long in a caustic state.

Calcium, the metallic base of the earth lime which forms more than a half of carbonate of lime.—It is unnecessary to dwell on the vast importance of the latter mineral, both as an economical substance and as a constituent of the earth's crust; but lime is also found as a component of another valuable mineral—sulphate of lime, or gypsum, of which it forms about $\frac{1}{4}$th part. Gypsum occurs in extensive beds in more than one geological formation; in America in the primary or Silurian, in England and Ireland in the secondary, and along the Medi-

terranean in the tertiary strata, divisions which will be hereafter explained. Lime also enters into the composition of a great variety of minerals.

Iron.—The mere name of this metal must recall to memory the multitude of uses to which it is applied, and justify us in regarding it as one of the greatest gifts of creative intelligence to man. In addition, however, to its occurrence in a mineral state in our coal measures, as clay iron-stone and also as spathic iron, both of which are carbonates of iron; in masses and in disseminated nodules as anhydrous and hydrated peroxide of iron, or red and brown hematite; in the magnetic oxide and in specular iron, or Elba iron,—minerals which are smelted as ores for iron,—it is found almost pure in masses of meteoric iron and in a vein traversing mica slate in North America. In combination as an oxide, it is extensively diffused, being found in small quantities in most minerals, and consequently in the soil of the earth's surface. It occurs in many springs, being dissolved as a protoxide by water charged with carbonic acid, and then again deposited as a peroxide, either at the bottom of marshes, as bog iron, or on the banks of the springs: and it is deserving of notice that this apparently simple operation is sometimes compound; the tangled masses of this substance, so frequently found in such situations, proving on examination to be the work of an infusorial animal, —the gaillonella ferruginea,—which thus interposes and reduces the mineral to an animal substance. This metal is also found in the colouring matter of the blood, of the hair, and of many other tissues, animal and vegetable, and its uses are not therefore limited to the great works of art,—the machinery of civilized social life,—but may be traced in the many charms which are shed over life itself, by the varied colours exhibited, under the control of creative power, in the petals of the flower, the egg and feather of the bird, or the skin of man and other animals.

Manganese enters into the composition of a great number of minerals, though often in a very small quantity, forming, in such cases, their colouring matter. It is also found in the ashes of

plants and the bones of animals. It is used in the arts,—for preparing chlorine by the action of its peroxide on hydro-chloric acid, and oxygen by the action of the same oxide on sulphuric acid; as also to deprive glass of its colour by the oxydating action of its protoxide, or to colour it purple by its deutoxide.

These, then, are the simple elementary substances which have been combined together in that portion of our globe which, by the long-continued action of meteoric agencies, has been reduced to a condition suited for the support of animal and vegetable organization; and they will next be considered in the mineral compounds which form the strata of the earth. These are few in number, for creative power having combined a few elements into a great variety of forms, just as we observe in the organic world in which many substances, both animal and vegetable, possessed of the most opposite qualities,—some being alkalis, some acids, some poisons, some wholesome food,—have all been compounded of the four simple elements, carbon, oxygen, hydrogen, and azote. One point, however, is here deserving of especial notice, as bearing on the great question of the former condition of our globe; namely, that $\frac{2}{3}$rds of the ponderable matter of the earth's crust, taking into consideration oxygen, hydrogen, and carbonic acid, have existed, or been capable of existing, in a gaseous state.

The principal minerals which enter into the composition of rocks, and of stratified beds, are—quartz, felspar, mica, augite, hornblende, oxydulated iron, carbonate of lime, sulphate of lime, double carbonate of lime and magnesia or dolomite, chloride of sodium or rock salt, coal, and lignite. Many other minerals occur occasionally in rocks and sedimentary deposits, and impress upon them a consequent peculiarity, such as garnet in mica schist, tourmaline in some varieties of granite, flints in chalk and other calcareous formations, iron pyrites and carbonate of iron in shales, crystallized carbon or the diamond amongst the gravel and other transported or alluvial matter along the Ghauts in India (especially at Golconda), as also in Borneo and in Brazil; but these, as well as the vast

variety of minerals found in the basaltic and trachytic lavas of both ancient and modern volcanoes, and those either associated with metallic ores or isolated in mineral veins, although replete with interest to the Mineralogist, and often of great value to the carefully inquiring Geologist, are insignificant as to quantity, when compared with the minerals cited as the principal constituents of the earth's crust. The composition of these minerals may be represented iu a tabular form, as in p. 32, and to them, as principal elementary substances, may be added the alkali lithia, its name, derived from the Greek λίθειος, having been adopted from its first discovery in an earthy mineral, though it occurs only in small quantity in rocks. The metallic base lithium was obtained by Davy from the alkali; its equivalent is very low, 6·44, and its oxide has therefore a high saturating power. The discoverer of the alkali was Arfwedson, in 1818.

Rock salt is a compound of sodium 40·5 and chlorine 59·5, or according to the old view, 53·29 of soda and 46·71 of muriatic acid, but it is usually contaminated by a small quantity of extraneous substances,—the salt of Cheshire containing—

Muriate of soda .	98·32	Muriate of magnesia	0·02
Muriate of lime .	0·01	Sulphate of lime .	0·65
Undissolved matter	1·00		

Coal and lignite vary considerably in composition. Blind coal, culm, or anthracite, contains for example from 94 to 97 per cent. of carbon mixed only with mineral matter, as bitumen has either not been developed in it, or has been subsequently removed, though traces of vegetables have been discovered even in anthracite; it is therefore a non-flaming coal, and yielding an intense heat, is particularly valuable for the lime-kiln and similar purposes: the coal of Kilkenny in Ireland and the culm of Wales belong to this division. Newcastle coal is a flaming or bituminous coal, consisting, in the best varieties, of carbon 84·99, hydrogen 3·23, oxygen 11·78, bitumen having been developed in its substance by the action of oxygen and hydrogen on a part of its carbon. Lignite still exhibits the structure of wood, and may be considered a fossil charcoal.

In studying the minerals which are combined together in the rocky crust of the earth, attention must be paid to certain variations in the chemical constitution of a mineral which do not affect its external form—or, in other words, to the great doctrines of substitution by equivalents and of isomorphism. It is thus that substances possessing the same elementary constitution may replace each other in a mineral, without disturbing its principal or characteristic qualities; for example, alumina is possessed of the same elementary constitution as peroxide of iron, namely, it consists of 2 of base to 3 of oxygen, and can thus replace it; and magnesia, possessing a constitution of 1 of base to 1 of oxygen, can replace the protoxide of iron. In green and black augite this variation in the bases is well exemplified: as they contain,

Green augite,—magnesia 11·49 + prot. iron 10·02 = 21·51

Black augite,—magnesia 4·99 + prot. iron 17·38 = 22·37;

the actual composition varying whilst the formula of composition is preserved.

As it is difficult to convey fully to the mind of the student, by written description, the physical characters of minerals, he is recommended to obtain accurately named specimens, though a few remarks will be given, and may be of use when combined with the description of rocks.

Quartz is well known as rock-crystal, which is often called diamond, as Cornish diamond, Bristol diamond, Quebec diamond, although it has not the slightest relation to that mineral; and also as common quartz. The prevalent colour is white: when pure it is either transparent or translucent; when impure it is commonly opaque. Its lustre is vitreous, inclining in some varieties to resinous. The streak is white.

Felspar.—Prevailing colour white, sometimes grey, and in many granites and syenites flesh red; transparent, translucent, or almost opaque; lustre, vitreous inclining to pearly on the faces of cleavage. By observing the tendency to a resinous lustre in quartz, and to a pearly lustre in felspar, these two minerals may generally be distinguished from each other without difficulty.

An inspection of the Table will show that under the head Felspar is ranged a group of minerals connected together by general resemblance of composition, but named differently as potash, soda or lime becomes the leading base. Modern Mineralogists have in this manner subdivided the great group into sections; and this attention to the chemical variations of the mineral will doubtless be hereafter made an important help in studying the formation of rocks.

Mica.—Prevailing colours, white, grey, yellow, dark brown, or black; transparent and translucent, especially in thin laminæ; lustre, pearly; flexible and elastic when in laminæ, by which character it is distinguished from chlorite and talc. This remarkable mineral is at once recognized in granite, gneiss, and mica slate, by the brilliancy of its plates or laminæ.

Talc is distinguished from mica as being flexible but not elastic: in composition it differs from the presence of magnesia. Talc is one of a group of minerals which includes chlorite.

Augite.—Colour varying from green or grey to brown and black; generally opaque; lustre, vitreous inclining to resinous; brittle. This mineral is very common in volcanic rocks.

Hornblende.—Prevalent colour, shades of green, increasing in intensity up to black; generally opaque; lustre, vitreous inclining to pearly in light-coloured varieties. Brittle when isolated, but when massive frequently tough, and therefore difficultly frangible. It is an essential ingredient of syenite and greenstone, and often occurs in granite, gneiss, and other mountain rocks.

The two last-named minerals are reducible to the same chemical formula, as they are both bisilicates of lime and magnesia, in which a portion of the acid or silica is sometimes replaced by alumina, and a portion of the base by protoxide of iron, according to the law already noticed; they are also an example of dimorphism, the crystalline forms being different. The difference of geological position will enable the inquirer to judge in most cases whether he is examining the one or the other; but as it is sometimes very difficult to determine whether a rock should be classed with greenstone or with basalt, so

it is also difficult to distinguish between these two minerals. In general the species hornblende contains less lime than augite, and is less fusible; but as might have been supposed from the similarity of their elementary constitution, it is possible, by adopting certain conditions of heating and cooling, to change the external crystalline form of the one into that of the other; an experimental fact which has been used in explanation of the difference of their ordinary position.

Diallage, or *Schiller Spar*.—Colour, dark olive-green, inclining to pinchbeck brown; lustre, metallic; part of a group including bronzite and hypersthene, minerals which enter occasionally into the composition of rocks having the general character of hornblendic rocks.

Oxydulated Iron or *Magnetic Iron*, a compound, according to Berzelius, of 2 atoms of peroxide and 1 atom of protoxide of iron.—It is highly magnetic, and when massive, more so than any other ore of iron. Colour, iron-black; opaque; lustre, metallic. It forms extensive beds in Norway and Sweden: at Dannemora the beds are excavated to the day, the principal mine forming a chasm of 150 ft. broad, and 500 ft. deep. The amorphous masses of Siberia and the Hartz, which yield the most powerful natural magnets, may be associated with this species.

Carbonate of Lime, and also Double Carbonate of Lime and Magnesia, or Dolomite.—The presence of carbonic acid can always be determined by the action of an acid and the consequent ebullition produced by the escape of the carbonic acid. This is the easiest and most certain method of detecting limestone. *Sulphate of Lime* is distinguished from carbonate by not effervescing with acids; and from other minerals, whether in its fibrous or lamellar state, by its comparative softness.

Of salt, coal, and lignite, it is unnecessary to say more under this head.

Such then are the minerals which enter extensively into the composition of the earth's crust; and in order to form a clear idea of its present and past condition it is necessary to inquire under what combinations they usually occur.

SPECIES AND VARIETY.	Silica.	Alumina.	Lime.	Magnesia.	Potash.	Soda.	Oxide of Iron.	Oxide of Manganese.	Carbonic Acid.	Sulphuric Acid.	Water.	Fluoric Acid.	Lithia.
Quartz (when pure)	100	"	"	"	"	"	"	"	"	"	"	"	"
Felspar (green, of Siberia) . .	62·83	17·02	3·00	"	13·00	"	1·00	"	"	"	"	"	"
Do. (Carlsbad)	64·50	19·75	trace.	"	11·50	"	1·75	"	"	"	0·75	"	"
Do. (soda or Albite, of Finbo)	70·48	18·45	0·55	"	"	10·50	"	"	"	"	"	"	"
Do. (Albite, of Chesterfield) .	70·68	19·80	0·23	"	"	9·06	"	"	"	"	"	"	"
Labradorite	55·75	26·50	11·00	"	"	4·00	1·25	"	"	"	0·50	"	"
Mica, or talc-mica, (Zinnwald)	47·00	20·00	"	"	14·50	"	15·50	1·75	"	"	"	"	"
Do. (2nd Zinnwald variety) .	46·23	14·14	"	"	4·90	"	17·97	4·57	"	"	3·73		4·21
Do. lepidolite (granular or scaly mica)	50·35	28·30	"	"	9·04	"	"	1·23	"	"	5·20		5·49
Talc	62·00	1·50	"	27·00	"	"	3·50	"	"	"	6·00		"
Augite (green)	54·08	"	23·47	11·49	"	"	10·02	0·61	"	"			"
Do. (black)	53·36	"	22·19	4·99	"	"	17·38	0·09	"	"	"	"	"
Hornblende (green, Pargasite)	46·26	11·48	13·96	19·03	"	"	3·43	0·36	"	"	"	1·60	"
Do. (black)	45·69	12·18	13·85	18·79	"	"	7·32	0·22	"	"	"	1·50	"
Diallage	41·00	3·00	1·00	29·00	"	"	14·00	"	"	"	10·0	"	"
Oxydulated iron	"	"	"	"	"	"	peroxide, 2 atoms; protoxide, 1 atom.	"	"	"	"	"	"
Carbonate of lime (when pure, as calcareous spar) . .	"	"	55·93	"	"	"	"	"	43·58	"	"	"	"
Sulphate of lime (gypsum) .	"	"	33·00	"	"	"	"	"	"	44·80	21·00	"	"
Do. (anhydrite)	"	"	41·75	"	"	muriate, 1·00	"	"	"	55·00	"	"	"
Dolomite (by Thomson) . .	"	0·68	30·54	22·91	"	"	1·69	"	48·22	"	"	"	"

A survey of any extensive portion of the earth's surface will generally bring before us two distinct forms of mineral compounds; one, in which the constituents occur in distinct crystals, which to the eye exhibit no traces of any previous wear, and produce therefore by their combination crystalline rocks; the other, in which the constituents have undergone wear, are either mixed together confusedly or separated into distinct beds, and, whether loosely aggregated or cemented together, indicate the action of various meteoric and mechanical agencies and produce rocks of deposition, whether mechanical or chemical. To the first class belong—granites, syenites, greenstones, basalts, gneiss, many varieties of mica slate, granular limestone; to the second—sandstones, conglomerates, shales, clays, compact limestones; and if these forms were always distinctly marked, the divisions would be sufficient and satisfactory: but when the crystalline rocks, formerly called primary, are closely examined, some of them are found to resemble the sedimentary, as for example, mica slate and clay slate, some varieties of which are little more than a highly indurated shale; and in like manner sedimentary rocks in the vicinity of ancient lavas are found to have undergone a change in their characters which assimilates them to the crystalline rocks, whence even the strata are full of organic remains; and on observations of this description the metamorphic theory has been established.

If the Geologist, having by a careful scrutiny determined the composition and physical characters of the various rocks he meets with, were to proceed to explain their occurrence on hypothetic assumptions, he would fall into the speculative errors of his predecessors; but he pursues a different course, and wisely determines to ascertain, by observation, what forces are still in action on the earth's surface, and what effects they produce on its mineral constituents. He thus studies in lavas issuing from volcanic craters the effect of igneous fusion, and in sand and mud banks, still forming, the effect of aqueous agency; he discovers in

the dislocating action of the earthquake, in the wearing action of the sea wave, in the accumulating labours of polypes, as exhibited in coral banks, so many auxiliary or modifying forces; he observes on the sea-shore the exuviæ or remains of shell-fish and other animals becoming invested in the deposits of sand or mud forming over them; and when he turns to the rocky strata of the earth now become dry land, he finds similar evidence of igneous action and of sedimentary deposition, and discovers animal remains imbedded in their substance.

The metamorphic theory facilitates the application of recent analogies in explaining the condition of crystalline rocks which may have proceeded from a species of fluidity, the result of direct igneous action, as in lavas, and probably in some granites and porphyries; or have been produced by the indirect action of heat on sedimentary deposits, continued for a long period and combined with pressure, as has been the case in the crystalline schists, and in some other strata in which a crystalline or semi-crystalline re-arrangement of the mineral particles has taken place, although the existence of organic bodies still demonstrates their former sedimentary character. By the careful examination of recent and still recurring natural phenomena these truths have been made manifest; and it is by the continuance of such examination that remaining difficulties will be removed. The change produced on mineral beds by contact with highly heated matter has been demonstrated, almost with mathematical precision; and though it is very difficult to decide its exact limitation, we can never satisfactorily study the strata of the earth without referring to it. And if the metamorphic theory thus aids us in studying the varying mineral conditions of the earth's crust, the organic remains still visibly imbedded in many of its beds demonstrate that changes equally striking have taken place in the successive organic inhabitants of its surface; in short, that there have been animal and vegetable as well as mineral epochs. The beautiful combination of facts on which Palæontology now rests, as one of the most sure bases of geo-

logical science, can only be fully appreciated by careful study; but in this brief memoir it is assumed as a fact, that at various epochs the mineral strata of the surface of our globe were disturbed deeply and widely, shales and slates, sandstones and conglomerates, limestones, &c., were formed, some in one place, some in another, whilst great modifications took place simultaneously in organic beings; and if this statement, which is founded on facts observed over a large portion of the earth, be correct, the evidence of the epochs of mineral change should harmonize with that of the epochs of organic change, and hence the study of the one may be made to assist that of the other.

This deduction has in a few years elevated Geology to the rank of a science; and it may be hoped that a more exact study of the operations of the great physical forces which still act and always have acted on the earth's strata, such as magnetism, diamagnetism, electro-magnetism, &c., as well as of the effects of a continued contraction of the earth's nucleus, will render it so practically exact, that not only the probability (under any conditions of strata) of discovering certain useful products may be stated, but the more abstract and obscure questions of mineral veins and of the distribution of metals be solved on sound principles.

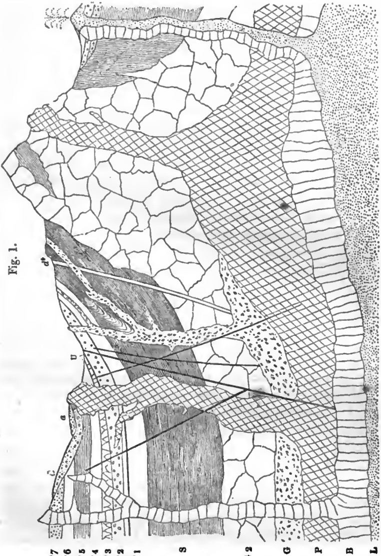
It may then finally be assumed, that as mineral matter is now brought in volcanoes into that state of semi-fluidity which allows of the crystallization of minerals, so at former epochs it experienced a similar fusion, and hence that truly igneous rocks existed at such epochs, and were brought nearer to the surface, or even erupted;—that, in a similar manner, the changes produced by slow igneous action under great pressure, having been observed in strata contiguous to modern and ancient lavas, they may have occurred in strata contiguous to other igneous rocks, and have given rise either to schistose crystalline rocks in all their varieties, or to some simpler modification of the structure of sedimentary deposits;—and finally, that changes in the combinations of organic beings,

having been proved by extensive observations to have occurred at successive epochs; when any particular group of animals or plants has been studied in connection with the mineral strata of any one portion of the globe, it becomes a clue to determine their relation with the strata of any other portion in which organic constituents have also been discovered. The certainty thus attained constitutes the value of Geology as a practical science; and though much caution is yet required to remove mere varieties from the lists of characteristic fossils, and to determine the actual limits of species, it must be admitted that the modern applications of the science have been both useful and satisfactory.

A general representation of the combined theories of igneous rocks, metamorphic rocks, and fossiliferous deposits, is given in the ideal diagram, fig. 1, extracted from Cotta. In the diagram, granite is represented as an igneous rock near to the surface, and having its origin at no great depth; and that this is probably the true state of the case will be subsequently shown, the low specific gravity of ordinary granites, which varies from 2·5 to 2·7, whilst that of the lavas of Ætna, Stromboli, and Vesuvius, is 2·9, and that of basalt above 3, being a strong argument against their formation at great depths, or under great pressure. The chemical investigation of the composition of rocks as compared to that of their separate mineral constituents, which is now much attended to, is beginning to throw new light on their relations to each other. Plutonic rocks are eminently silicious or quartzose, and volcanic rocks felspathic, and it has been shown that the low specific gravity of the former is closely connected with this excess of silica. It is therefore by no means improbable that granites may have been formed from the liquefaction of crystalline stratified rocks, which they so closely resemble in composition, if not of sedimentary deposits.

Theoretic Section of the Earth's Crust.

Fig. 1.



L Lavas ancient and modern.
B Basalt.
P Porphyry.
G Greenstone.
G 2 Granite.
S Crystalline schists.
F 1 Cambrian and Silurian.
F 2 Devonian and Carboniferous.
F 3 Magnesian limestone.
F 4 Trias or new red.
F 5 Jura, including lias.
F 6 Cretaceous.
F 7 Tertiary.
d Diluvium or drift.
a Alluvium.
U Mineral veins.
dk Dyke.

CHAPTER III.

Geological Formations—Their Meaning, Object, and Utility—The Mode of Studying them, and the Physical Phenomena they exhibit.

An inquiry into the actual condition of the earth's crust has made known to the Geologist, as stated in the preceding chapter, that the mineral matter of which it consists must, from the great variety of its characters, have been produced under circumstances equally varied. He has thus been led to trace in variously alternating beds or strata, however indurated, a close resemblance to the muds, sands, and gravels now accumulating at the bottom or on the shores of the existing seas and lakes, and to compare the ancient limestones with the calcareous deposits and the coral banks of tropical seas; he has discovered the affinity between lavas now erupted by still active volcanoes and the streams poured out either sub-aerally or sub-aqueously by the volcanoes of other times, and has ascertained that crystalline massive rocks, granites, syenites, and porphyries, were brought to the surface at various distinct epochs, and were therefore connected with distinct historic periods of the earth's changes; and finally, he has observed and exemplified the alterations effected in the structure of mere sedimentary deposits by the combined action of heat and pressure, which have produced that crystalline structure so common in the metamorphic rocks. The knowledge thus acquired and the proofs obtained of a certain sequence and progression in mineral deposits, would not alone have enabled the Geologist to determine that the alternating disturbances and changes they shadowed forth were events antecedent to Man's occupancy of the earth: but he has

found in his researches other evidence, and whilst apparently engaged only in the examination of the mineral structure of the earth, has fallen upon the traces of its former inhabitants, in the many shells and other organic relics imbedded in its strata; and though yielding to a natural impulse, he first called them by names, such as cockles, &c., which assimilated them to existing shells,—just as "the emigrant to a foreign clime bestows on its fruits and flowers the names familiar to him in his own,"—and attributed their anomalous position on land to the Deluge, it was not possible that a careful scrutiny of the circumstances under which they occurred could long leave him without a suspicion of their true bearing on geological history. When, for instance, the inquiry was extended from such fossils as were scattered over the surface or were imbedded in loose strata to those which were so intimately mixed up with mineral matter as to form an essential part of vast accumulations of solid rocks, as slates, limestones, &c., it became evident that no single cataclysm or event could account for their existence in such a position. More careful investigation, whilst it explained the changes which had affected their mineral condition, discovered also differences in organic form and structure, until at length the prejudice which still sought to explain such supposed anomalies by the *plastic power* of Nature was dispelled, and the magnificent truth became apparent and recognized, that Geology teaches the history of past as well as of present creations. This truth, though previously imperfectly developed, was first set before the British student in a clear and distinct form by the late William Smith, who, having with great labour traced out the continuity of many of the British strata and studied the peculiar fossils which each well-marked stratum contained, announced as facts—that

1. The fossils found in any stratum are the relics of animals living at or about the time when that stratum was deposited or formed.

2. The strata not being parts of one confused mass, but fol-

lowing each other in a distinct progression, and the differences of their mineral character indicating marked differences in the conditions of deposit, it must be assumed that the animals which supplied the organic relics they contain lived at successive, and often widely separated epochs.

3. As the organic differences observable in these relics of animals of other times exceed in amount and kind any probable, nay possible, variation of specific characters proceeding from the influence of local circumstances, it must be admitted that at each stage of the earth's history there was a distinct and peculiar assemblage of organic beings which, from causes not clearly known to us in a final sense, became extinct and were replaced by others.

Geology therefore explains to us the history of the organic as well as the mineral changes of the earth, and having established a connection between the two at various epochs, embodies the knowledge thus acquired in a distinct shape, as expressed by the term 'Formation,' which implies 'A History of the organic and inorganic conditions of the earth's surface at any given epoch,' not limited by time, but by circumstances; so that the term 'Silurian Formation' implies a history of the changes which took place in the earth's surface, of the volcanic eruptions, the various deposits formed by rivers, lakes, and seas, the modifications effected by the action of currents or the beating of the waves of the sea, and of the animals which contemporaneously existed, at an epoch which, though we cannot state its antiquity by years of time, was evidently, by the position of the strata, posterior to some and anterior to other formations.

The practical utility of geological formations when thus established, is this, that having once ascertained that the conditions of the earth were favourable at particular epochs to the production of certain mineral changes and the existence of peculiar organic structures, and that creative power had called into existence the animals and plants which were suited to such conditions, and left them imbued with powers of en-

during only a limited amount of change, it becomes practicable to proceed in an inverse order and to determine the geological age of any stratum from the relics of animals and plants it contains; and even to use the knowledge of the condition of the earth's surface at a particular epoch, which is derived from a study of the organic remains of the strata formed within it, to estimate the probability of finding other substances whether mineral or organic, metals or coal, to the existence of which that condition appears equally favourable.

PHENOMENA OF ROCKS.

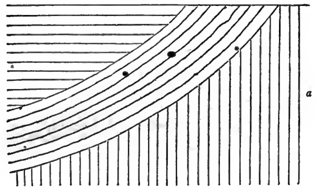
Before proceeding to the study of formations, the relative order of which can be determined by comparing together the natural history of each, that is, the fossils contained or buried in successive strata, it is desirable to notice those phenomena, or accidents of strata, which have materially aided in first establishing the fact of succession, and must still be consulted in all doubtful cases of position.

STRATIFICATION.

Many rocks exhibit a lamellar arrangement throughout their mass, which produces a schistose or slaty structure sometimes related to the greater planes of supposed deposition, sometimes to a plane intersecting that of deposition, and called the plane of cleavage. In the first case the structure may be the result of original deposition; in the second, of subsequent or metamorphic modifications. In all cases where rocks are observed to consist of distinct layers, lying one over the other, and each having a considerable extension, they are said to be stratified. If this stratification had been found every where uniform, it might have been assumed that deposition had gone on regularly and without disturbance; but stratification is often very irregular, both in the thickness of the beds and in their position and direction, and therefore it must be inferred that some interfering cause has disturbed

and modified their deposition. Again, if to a succession of beds having a considerable inclination, called 'dip,' to the horizon, succeed other beds, perfectly or nearly horizontal, it is reasonably concluded that the first beds must have been tilted-up before the deposition of the undisturbed horizontal beds, and thus an epoch of disturbance or separation is established; the terms conformable and unconformable being applied to the strata as they preserve or lose their parallelism.

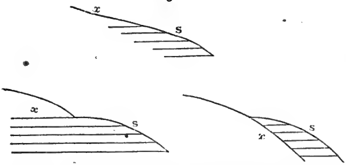
Fig. 2.



Thus *b* is unconformable to *a*, and *c* is unconformable to *b*, whilst the beds of *a*, *b*, and *c*, are conformable within themselves.

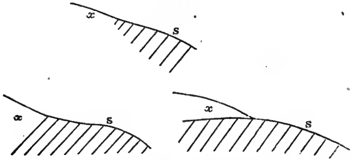
As the true position of every bed or stratum in the system to which it belongs must be first determined from the actual order of superposition, although fossils may be subsequently used to clear up occasional obscurities, the great importance of accurately studying stratification is evident; and the occasional difficulties which are met with in the investigation may be estimated from the following examples, in which the most ordinary cases of doubtful superposition are exhibited. It is very possible also that the difficulties may be complicated by contortions extending only through the lower portion of a mass, and producing an apparent but not a real unconformability.

Fig. 3.



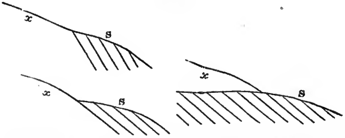
In fig. 3 the portion *x* may be found either to overlie or to underlie the stratified beds when sufficiently opened to show the connection.

Fig. 4.



In fig. 4, though *x* overlies the stratified beds, it may be found either conformable or unconformable to them.

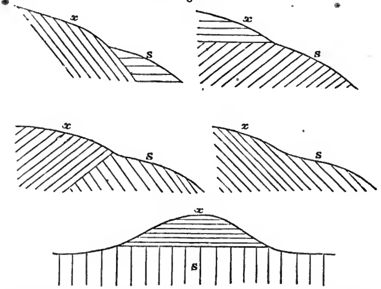
Fig. 5.



In fig. 5, *x* may either underlie or overlie the stratified beds.

x has in these cases been represented as itself unstratified; it may, however, be also stratified, and then the following example will show the possible results.

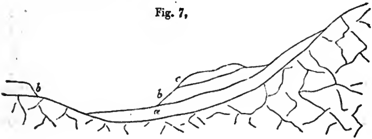
Fig. 6.



In all of which x is unconformable to s, excepting in the fourth, where it is conformable to s, although possibly of a different mineral character.

It will be observed from these examples how much caution is required in determining the exact conditions of stratification, and in not too hastily deciding that a rock is older or younger than another from its *apparent* position; and this is shown even more distinctly in

Fig. 7,



where *a*, though generally lower in natural position, as it is older in geological age than *b*, rises up from below it to a higher level; and again *b*, though underlaid by *a* at one point, rests itself directly on the subjacent rock at another, and might be even, from a mere comparison of levels, supposed to underlie the elevated portion of *a*.

Strata are frequently undulating on the large scale, though, when examined at any one point, they appear to have a uniform inclination.

Fig. 8.

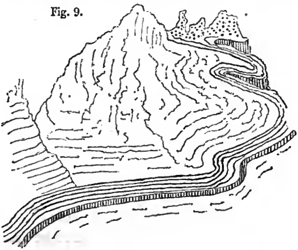
This arrangement may be due either to original deposition on a previously modified surface, or to gentle movements of the underlying mass prior to the consolidation of the overlying strata. The crest or ridge transverse to the highest point of each bend, as here shown in section, forms the anticlinal line nearly in the direction of the strike, and a line running in a similar direction along the hollow is the synclinal line.

FLEXURES AND CONTORTIONS OF STRATA.

The undulations above noted are simple, but flexures and contortions of strata of the most striking kind are often exhibited on a grand scale, as in fig. 9: to illustrate them Sir James Hall made the following experiment. Several layers of clay were placed under a weight, and their opposite ends having been pressed by considerable force more closely together, it was found on the removal of the weight that the layers were curved and folded so as to resemble, in miniature, the natural strata. Other illustrations have been proposed, but it may be remarked that in all of them the materials acted upon are supposed to be flexible; whereas in the crystalline schists, the contorted strata are now so hard

and brittle that they could not be supposed capable of assuming such forms without being shattered, or at least extensively cracked at the bends. That internal movements have

Fig. 9.



taken place, even in the most indurated strata, may be admitted; and that one stratum has sometimes been forced over another, the surfaces being broken up and formed into a breccia, seems evident from the brecciated structure of some strata; but in many cases we can scarcely doubt that the now highly indurated and crystalline strata were, at the period of flexnre, soft and pliable.

In the Carpathian chain, metamorphic rocks including gneiss, mica schist, talc schist, clay slate, associated with syenite and porphyry, are succeeded by an extensive formation of sandstone. Intercalated with this rock, at various places, are beds of limestone, which, from their fossils (ammonites, &c.), have been considered either a member of the green-sand, which would place the whole in the cretaceous system, or a connecting link between the oolite and the chalk. In either case the formation is comparatively recent, and as it comprises clays and limestones with the sandstone, is very favourable for studying both the mechanical effects of pressure and those

of metamorphism. For example, some of the schistose clays have become silicious slates, with occasional veins of cinnabar, the marls have been converted into jasperoid rocks, and the sandstones either into quartz rock or into highly quartzose grit full of pyrites, whilst the mechanical changes during this metamorphic action have been as striking as those exhibited in the Alps in similar strata and shown in fig. 9, already referred to. In the tertiary beds of Sicily, where thin beds of solid gypsum are interstratified with bent and undulating gypseous marls, the solid beds have been broken into detached fragments which still preserve their sharp edges, while the continuity of the more pliable and ductile marls has not been interrupted; an example equally illustrative.

In endeavouring to explain these phenomena as reasonable objects of scientific research, too great a stress must not be laid on any one cause of change to the exclusion of others. There can, for instance, be little doubt that many minor contortions, and some flexures in strata, are the result of their original deposition on banks and amidst the eddies of currents; but we cannot ascribe the flexures in the Alps, where, as Lyell observes, "curves of calcareous shale are seen from 1000 to 1500 feet in height (fig. 9), in which the beds sometimes plunge down vertically for a depth of 1000 feet and more, before they bend round again," to such a cause, and must consider them striking evidences of disturbance from internal movements; a subject to which reference will be again made.

The preceding observations are sufficient to show the care with which it is necessary to trace the order of superposition of strata, and to guard against the ambiguity produced by undulations and disturbances of stratification, and sometimes increased by 'Cleavage,' which will be now considered.

CLEAVAGE (JOINT-LIKE AND SLATY).

In stratification the beds are the result of successive de-

posits during a period of time which may have included many exhibitions of disturbing forces. It is thus that some strata may have been broken up, elevated, or depressed, prior to the deposition of others, producing one or other of the cases of stratification described; but forces which have caused a geueral corresponding strike in the stratification for hundreds of miles cannot be considered local,—they are general, and fall into the class of great physical forces which affect the earth as a planetary body. As in a future chapter they will be discussed in respect to elevation, it is only here necessary to observe that the forces which have produced the more marked ridges of stratified deposits appear to have acted in lines related to the great circles of the earth. In endeavouring to discover the limits of successive beds of sedimentary deposits, other planes than those of deposition are met with, and it is often difficult to decide which is the true plane of stratification, and which the plane of cleavage. There has been much obscurity on this subject, but accumulated evidence now leads to the conclusion, that the direction of cleavage is due to the same general causes which affect stratification, as Mr. Sharpe has specially shown in his examination of the effect produced on the form of fossils. Clcavage planes are often parallel over a large space of country, cutting through several distinct geological formations, independently of the contortions or undulations which the strata have undergone, and of the original bedding, the dip of the strata being to the S. E., and that of the cleavage perhaps to the N. W., or *vice versâ;* whilst the strike of both may be nearly the same. Again, the dip of the plane of stratification and that of cleavage may both be to the S. E. or N. W., and yet the angles of their dip may be very different. In some cases cleavage may assume a fan-like form, the strike still continuing nearly uniform with that of stratification, so that the disturbing forces appear to have acted at successive epochs, nearly in the same direction. In addition, however, to these great disturbing causes, the consideration of matter under heat and pressure would induce

cleavage of a different character, and it is thus that cross cleavage, being one form of the joint-like cleavage of massive rocks, has been probably produced, and frequently also the lamination or slaty cleavage of slate rocks. The observer will generally be able to clear up this difficulty by discovering the plane of deposit of particular fossils, or of beds of flints and pebbles; and if these be wanting, of layers of clay or of sand, differing in character from the principal mass he is studying. In stratified deposits, the direction of the planes of stratification, as they crop out in the cliffs on one side and slope away on the other, impresses a distinct character on the surface of the country; whereas cleavage, being abrupt and frequently at a high angle, rarely does so, although the actual direction of great ridges, which is often not quite coincident with the strike of the bedding, is due to the same cause as that which produced cleavage. On the other hand, the great lines or ridges of strata are often cut through by cross cleavage, and a passage given to rivers across them; deep narrow dells being the frequent result of cross cleavage, whilst wide and open valleys are more generally the result of stratification modified by elevation. The smaller description of cleavage or slaty cleavage which has been alluded to as probably resulting from a polarizing action during the consolidation and metamorphism of strata is very remarkable in slates, which are frequently fissile in directions not parallel but transverse to the stratification; and something similar may be observed in the diagonal lamination of sandstones and of the more recent detritic (diluvial) deposits, which may be ascribed to a modification in the arrangement of the particles during the process of deposition.

DENUDATION AND WEAR.

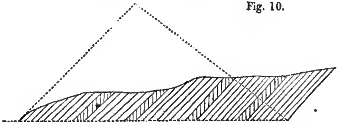
The term denudation strictly means the act of laying bare, though geologically it represents the result of that operation; so that a valley is said to be a valley of denudation when it has originated from the removal of a large mass of superincum-

bent strata and the consequent denudation of the underlying rock. In reality this is only one form of the general problem of wear, and yet it deserves especial attention, as being peculiarly calculated to awaken a lofty conception of the vast effects produced by the most simple natural causes, and to connect together the operations of the present and of the most distant epochs. If it be asked what has been the amount of denudation, the reply should be with Lyell,—that it may be measured by the whole mass of our stratified deposits, as they have all been detached and removed from their primeval positions. If the question be, "At what time did it commence, and how often has it been repeated?"—that its commencement must at least have been anterior to the deposition of the crystalline schists of the earliest epoch, and that it has been repeated during every successive epoch of the earth's history. Such considerations as these will enable the observer to form a just estimate of the magnitude of the phenomena before him, and will relieve him from that hesitation to admit their possibility which is the consequence of a cramped perception of the forces which produced them. In no other science is this power of philosophic generalization so important as in Geology, as the observer is constantly required to pass from the contemplation of very simple facts to that of great results; though at first he is perhaps disinclined to admit or even unable to comprehend the connection between them.

In studying the denudation or wear of the crystalline schists, a solution is obtained of a difficulty which led into error even Playfair, who, when discussing the probable thickness of the known portion of the earth's crust, estimated it from that of successive outcropping strata. For example, in a mica schist district an unbroken series of strata may be traced for probably 50 or 60 miles, dipping at an angle of 30° or 35°; and if it were assumed, with Playfair, that all these beds were originally deposited one upon the other in a horizontal position, and subsequently elevated by a disturbing force, the thickness deducible from such a consideration would be very consider-

able. No. 10 represents a section through strata which have for 30 miles a dip of 30°; now if this deposit had been once horizontal, and then simply tilted up, the thickness would be 30 sin. 30°, or 15 miles, and the edge of each stratum must

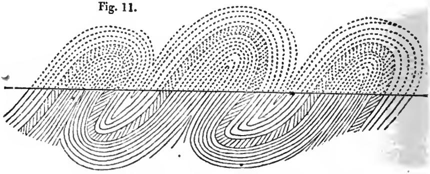
Fig. 10.



have been raised about 12 miles above the horizontal plane. With a dip of 45°, not unusual in the crystalline schists, the thickness would have been 21 miles, and the rise of the stratum edge 15. Though the inclination of strata has sometimes resulted from original deposition on banks, it must be ascribed principally, in this description of strata, to subsequent disturbance, as is proved by the frequency of contortions in all districts of gneiss and mica schist. Whoever, indeed, has carefully examined such districts must have noticed the repeated alternations of certain sets of strata, such as quartz slate, thick beds of quartz with micaceous specks, granitiform gneiss, mica schist passing into gneiss, mica schist passing into clay slate, layers and beds of granular limestone, &c.; which, if all considered independent and successive beds, would imply first an extraordinary amount of variation in the forces acting during their production without any great disturbance, and then the action of some great and controlling force, sufficient to modify the whole mass through a thickness of 30 miles, disturbing and elevating it at the same time; whereas a lateral pressure, whether produced by the undulating movement of the still liquid nucleus of the earth or by intrusion of liquid igneous matter, explains the phenomenon in a more simple way, by representing these alternations as

foldings of the strata in contortions, many of which are still visible, whilst others have been truncated by denudation, in the manner shown in No. 11, the surface having been further modified, by subsequent wear and the removal of the softer strata, so as to form mountain and valley.

Fig. 11.



Contorted strata, removed, above the line, by denudation.

Undulating beds were frequently formed during the carboniferous period, and the descending or dipping portions have sometimes been so perfectly truncated by denudation as to exhibit on the surface of the soil a horizontal plane. In the shales of this formation, numerous striking examples may also be found of wear, prior to the deposition of the overlying beds, by which the observer is enabled to trace the direction of the current which produced them.

The section by Dr. Lusser, taken in the Alps from St. Gothard to Asti, on the Zugersee, part of which is shown in fig. 9, is replete with fine examples of contortions. The strata, although greatly changed by metamorphic action, are not older than the secondary period, as they contain cretaceous fossils: they are, however, in immediate connection with crystalline schists, especially gneiss; and it seems probable that some partial modification of structure, whether from heat or other cause, must have preceded disturbance, and have rendered them sufficiently tenacious to undergo contortion, which extends to bends of 2000 feet in extent. The

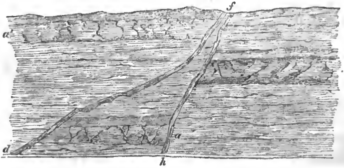
hollows cut in their summits mark also the great denudation which has been effected at points now so elevated.

The contemplation of such facts prepares an observer to expect the vast amount of denudation he will find displayed before him. It has gone on at all periods, and wherever one formation is laid bare by the removal of the overlying strata, evidences of its previous wear may be discovered.

FAULTS.

The preceding phenomena have implied lateral movements and pressure, accompanied or followed by extensive denudation or wear. The present are the result of vertical movements, by which whole masses of dislocated strata have either slid down or been forced up, the same strata appearing thus, as if repeated, at a higher or lower level. In this case, then, the retaining force is lateral, and the moving force either directly vertical, or indirectly so, as the result of lateral pressure; and it is probable, from the frequency of faults in shale districts, that the sliding was similar to that of land-slips. In fig. 12, the bed *a* has been first up-thrown along the line or fault *d f* to a^1, and subsequently down-thrown along the fault *f h* to a^2, the corresponding portion of *a* being depressed below *h*.

Fig. 12.



Although great and striking, the actual amount of vertical disturbance, as exhibited in faults, is generally small as com-

pared with that of lateral as displayed in contortions. In the Newcastle coal district, the upward or downward movement has amounted to nearly 1000 feet, so that the surface must have been originally affected to that extent, portions having been either raised or sunk 1000 feet above or below the rest. The projections or inequalities produced by such movement have been subsequently removed by denudation, and their former existence can only be discovered by studying the internal structure of the disturbed strata. In addition to the forces which have tended to elevate or depress the crust of the earth, and either to disturb and contort the strata by forcing molten mineral matter amongst them,—or, in the case of faults, first to fracture and then to separate one portion of them vertically from the other,—another may be traced in the effects of unequal contraction on such varied substances, as it is highly probable that heat gradually accumulating at certain points dried the superincumbent strata of deposition, and caused them suddenly to contract and crack. On every side, then, and at every level, whether we look at the varied surface of our earth as it now exists, and as it is now exposed to the incessant wear of rains, of torrents, of rivers, and of seas,—or seek our information of its condition within the deep recesses of the excavated mine,—we find the same tale narrated, of continued disturbance and wear on the one hand, and of renewed formation on the other.

FURTHER EFFECTS OF FORMATIVE AND DESTROYING CAUSES AS EXHIBITED IN MODERN AND ANCIENT SEA CLIFFS, SEA BEACHES, GLACIERS, AND ICEBERGS.

So long as the worn materials of the earth's original crust are studied only in deposits which afford no evidence of the existence of air-breathing animals and plants, it is not to be expected that the action of waves on the sea cliffs, which depends on a partial exposure of their surface above the level of the sea, should be discovered. The vast beds of sandstone and conglomerate which occur at certain geological

epochs are records both of wear and deposition, of which the simplest analogue will be found in the accumulations of sand and gravel which now form submarine banks. The extent of known sea banks, such as the banks of Newfoundland and the Bahama bank, is sufficient to support and confirm such an analogy; and when it is considered that soundings of only moderate depth are obtained on these banks in the midst of the ocean, they may be fairly considered as analogous to and commensurate with any of the more ancient banks which now constitute our beds of conglomerate or of sandstone. Ancient sandstones and conglomerates were indeed formed by the gradual accumulation and alternation of sand and gravel, just as our modern banks are formed and extended by the action of marine currents, combined with that of floating fields and bergs of ice, which have conveyed to and deposited on them the detritus of distant regions. In the hydrographic instructions issued by the Admiralty, it is enjoined that the deep sea lead shall be cast at convenient periods, even where no shoal is either known or suspected to exist; and much valuable data will be thus acquired for determining the progress and changes of such deposits. Every time the lead touches the bottom, a point of comparison is obtained, and a datum for future investigation secured; and when a shoal is first discovered, blame should not be imputed to preceding voyagers, as it is probable that in their time it had not been raised within the reach of ordinary soundings.

If it were in our power to examine the internal constitution of sea banks, the occurrence here and there of the trunk of a water-logged tree, or even of the hard fruits of many plants, would be ascribed to drift; but if beds of lignite or fossil wood were discovered, we should infer from them that the bank had either been exposed to the air, and supported a growth of air-breathing plants, or had been formed in some ancient estuary, adjacent to rivers whose banks had been clothed with plants. In a similar manner, though the occurrence of fragments of anthracite in ancient rocks renders it

probable that other parts of the earth at the time of their formation supported a growth of plants, it does not prove that those individual rocks had been clothed with vegetation; whilst the existence of beds either of lignite or of coal in a formation does prove that its strata had either been covered with plants or were contiguous to other parts of the earth then covered with them. Such is the evidence afforded by the ancient beds of anthracitic and bituminous coal of the carboniferous and other strata, and of the lignites of the still more recent tertiaries; and as the occurrence of deep beds of coal marks the existence of forests of tropical plants prior to their deposition, it is proved that at a very remote geological epoch some portion of the earth's surface had already emerged from beneath the water,—a fact which is supported by the appearance even in the crystalline schists of that description of wear which is produced by the surges of the ocean, when beating on the shore they either shape out sea cliffs, or form gravelly and sandy beaches.

The old red sandstone which underlies the coal strata penetrates into the recesses of the mica schist in districts where the two are in contact, whilst the wear of the crystalline rocks, and the fragments broken from them and found in the old red sandstone conglomerates, show that the former had sometimes attained their crystalline condition prior to the deposition of the latter. The broken and rugged edges of the mica schist correspond to the wear of such a rock; and the beds of shale of the coal series exhibit wear still more strongly; for though it is often difficult to trace the cliffs or sea boundaries of these ancient periods, as most of the strata have again been submerged and covered by more recent strata, the presence of large pebbles of mica schist in the conglomerate formed in the ancient bays or recesses of that rock proves that the sea once beat against it, and the deep precipitous banks which are not uncommon in the carboniferous formation may be also ascribed to a similar action. In the case of Lough Erne, in Ireland, an ancient sea bottom is observable in the limestone

of its shore, which is covered with projecting corals, now exposed by the removal, from denudation, of the shale above it, just as the sea bottom in warm climates is covered over by corallines. Shore wear may be traced at every geological epoch; but after the deposition and consolidation of the chalk it becomes more apparent, as the strata subsequently deposited were less extensive and more local. Sir C. Lyell gives several examples of inland chalk cliffs which occur in Normandy, but none can be more striking than the curved escarpment of chalk which bounds the plain of Dungiven, in Derry, the tertiary clays with their marine shells occurring at its base, and marking in the most striking manner the boundary of a former sea bottom, at levels now raised by elevation 200 feet above the present sea, although the ancient sea cliff was, as the present one is, a chalk cliff. As we advance further, new evidences of continued change are met with in the occurrence of more modern sea beaches, which are now far removed from the action of the existing sea; and in the cave of Uddevalla, in Sweden, this change of level was long since established by the cirrhipeda found adhering to its walls, and identical with those which now attach themselves to the rocks of the sea shore. We are thus, by the combined evidence of mechanical wear and of organic fossils, carried back step by step to ages which, though beyond the reach of historic records, can thus be compared with the present; and when the organic links of identity can no longer be discovered, we can still trace in mechanical effects the working of similar causes up to the remotest epoch.

The enormous wear effected during the last pause of elevation prepares us to estimate that of former epochs; for example, the wear displayed by the present condition of Portland Island, now cut off from the main land by the removal of an underlying blue clay, and the consequent undermining of its more solid strata. At present, the Chesil Bank, an accumulation of sand and gravel, forms a natural breakwater, and lessens, though it does not stop, the progress of wear; but should another slight

elevation bring up the blue clay nearer to the water's edge, the wear will again advance with rapidity, and the island once removed, the Chesil Bank itself will speedily be destroyed, and the sea advance upon the main land. This case is of much practical value; the wear of Portland Island is delayed by the dip of the beds, which carries the subjacent clay to a depth beyond the action of the moving wave, and reduces the wear to that of the more solid rock: the Chesil Bank has been formed because the still projecting portion of solid rock checks the force of the current, and causes the deposition of the pebbles moving with it: the pebbles of the bank protect the subjacent clay from further wear, and thus the general tendency is to preserve a tottering equilibrium, which the slightest change will destroy. In this instance a renewal of elevation would lead to renewed destruction; in others, elevation may bring up a solid stratum and thereby retard destruction, and these varying results must have attended elevation at all geological epochs; and again, if elevation stops for a period extensive wear by bringing up and opposing to the efforts of the sea a firmer rock, depression produces the same effect by removing a soft stratum from its action, as it did at Portland, where the removal of the blue clay beyond the action of the waves was probably the result of a depression. In examining any coast, therefore, with a view to judge of its probable permanency, the following particulars should be especially noticed: 1st, the nature of the shingle or gravel, as showing the direction of prevailing currents; 2ndly, the prevailing and most powerful winds; 3rdly, position and character of any sheltering barrier in respect to the prevailing winds; 4thly, position and character of any barrier opposed to the prevailing current.

The ancient or raised beaches of former and not very remote epochs are also examples of the effects of these modifying causes, and without doubt many such beaches have been swept away; an alteration of level, by elevation or depression, having favoured the work of denudation. The processes of wear on the one hand and deposition on the other can indeed

only rest in an equilibrium when the forces producing them are in a state of balance; and any alteration in the one must lead to a change in the others.

Vestiges of ancient river as well as lake wear may also be discovered: of the former, an example is given in fig. 13 and fig. 14, at the end of the chapter, in which the former bed of the river Burnthollet, county of Derry, appears to have been 10 feet higher than its present course, as shown by the remarkable masses of rock still remaining to attest the ancient wear of its waters: of the latter, the parallel roads of Glenroy, so often quoted, may be again cited here. These roads are ancient shelves or beaches, formed at the margin of a former lake, and at levels corresponding to its successive depressions. The highest is 1250 feet above the sea, the next about 1000, and the third 50 feet lower. Sir C. Lyell remarks, that "among other proofs that the parallel roads have really been formed along the margin of a sheet of water, it may be mentioned, that wherever an isolated hill rises in the middle of the glen above the level of any particular shelf, a corresponding shelf is seen at the same level, passing round the hill, as would have happened if it had once formed an island in a lake." The great lakes of America exhibit similar lake beaches at various elevations above their present surface; the absence of marine shells concurring with other circumstances to remove such accumulations from the list either of ordinary marine beaches or of sea banks.

But in addition to gravel deposits of this kind, the researches of Agassiz have added others,—the effects of ancient glaciers. It has been long known that these vast accumulations of frozen snow are in motion, proceeding from the higher valleys of the Alps, where they are formed, to the lower, where they are gradually melted; the portion cut off or melted at the lower end being replaced by a new mass added at the upper end. As it moves along, the glacier carries with it the fragments of rock which, having fallen from the precipices above, are arranged upon it in lines of deposit, to which the name of moraine has

been given. M. Agassiz distinguishes three varieties,—lateral, in which the moraine borders the valley of the glacier, resting either on its surface, or between it and the side of the valley; —medial, in which the moraine is formed of a long line of débris stretching, like a riband on the surface of the glacier, down the course of the valley;—terminal, in which the moraine is seen at the lower or terminal end of the glacier. These forms of gravel deposit, interesting as regards the history of the glacier itself, become still more so when applied to the explanation of gravel deposits, now no longer connected with glaciers.

It will be readily conceived that any considerable variation in the temperature of the air must produce a similar variation in the amount of snow and ice, and an augmentation or a diminution, as the case may be, in the glaciers resulting from them. Within very recent times, the variation has been towards an augmentation of cold, as shown by the inquiries of M. Venetz on the variations of the temperature of the Swiss Alps; but if compared with still more ancient epochs, the evidence is in favour of a rise of temperature. M. Venetz establishes the first of these positions by historical monuments and documents, which prove that some of the Alpine passes, now scarcely practicable, were then the ordinary lines of communication. In the archives of the Commune de Bagnes, M. Rivaz found the record of a legal process between that commune and the commune of Liddes, relative to the possession of a forest then on the territory of Bagnes, but which has since disappeared and been replaced by a glacier, now entirely cutting off the communication.

Many other examples are cited of the extension of the glaciers within the last 200 years; but the amount is small when compared with their vast extension, as proved by the existence of ancient moraines, in periods beyond the reach of historical records; for, as M. Agassiz observes,—"we shall be forced to admit that many moraines, far distant from existing glaciers, must have been formed at the most remote periods, if not anterior to the creation of man." The careful

examination of those deposits, which he thinks may be classed with moraines, has led him to trace, assisted by other phenomena of glacial action, the former existence of glaciers in countries now far removed, by their comparatively elevated temperature, from the sphere of their production; and he has thus brought the British Islands within the range of ancient glacial action.

Such inquiries and reasonings lead to the belief that there was a period of intense cold, when ice and snow were spread over a large portion of the northern hemisphere; and if on the lands of that frozen epoch, the glacier descended, as it now does in Spitzbergen, to the sea, icebergs and floating sheet ice must have been also formed, and the sea covered with them. Glaciers were the carriers on land of those fragments which formed ancient moraines;—icebergs and floes were the carriers on sea of those vast fragments which now as 'erratics' are dotted here and there along the course of the then marine current, just as the modern floe or iceberg now leaves at the bottom of the ocean, where it grounds and melts, the fragments of rocks it has carried along with it. This period of intense cold is called by Geologists the glacial epoch, and it is very remarkable that no traces of glacial action have as yet been found in the earlier strata.

It is thus that the Geologist, in endeavouring to trace out the sequence of stratified deposits, has been led to discover and examine the various changes which the earth's crust has undergone at successive epochs. He has seen sea and land alternately rising and sinking before him; and standing, as it were, unmoved on a rock, has watched and recorded the effects of each movement as it rose and fell. He is now, therefore, in a condition to compare together all the results he has observed, and to frame into one system the mineral and the organic histories of the earth's changes, as recorded in the strata of deposition.

Fig. 13.

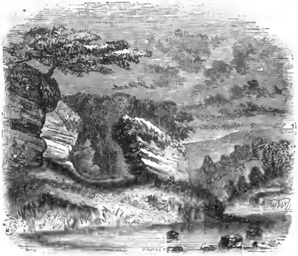
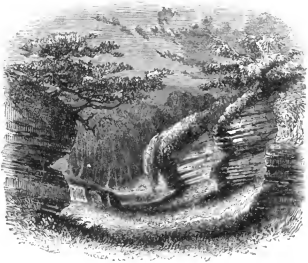


Fig. 14.



CHAPTER IV.

Plutonic, Metamorphic, and Volcanic Rocks—Condition and Temperature of the Interior of the Earth—Dykes—Elevating Forces—Veins—Metallic Deposits—Economic Value and Uses of the Rocks described.

In passing from one epoch of deposit to another, rocks have been observed, which, being crystalline and massive, have evidently undergone igneous fusion, and yet do not resemble volcanic rocks; others which, though crystalline, are as regularly stratified as sandstones and shales; and others which are readily recognized as volcanic products.

These rocks are the subject of this chapter, as it is necessary that the Geological Student should be made more fully acquainted with their nature, and with the circumstances connected with their production.

FIRST GROUP.

The remarkable group of Plutonic rocks may be associated as felspathic with the well-known rock called granite, of which felspar is an essential constituent.

Granite, common.—Felspar, quartz, and mica, disseminated in nearly equal proportions; the felspar lamellar, and the texture often granular. Tourmaline and hornblende are frequently accessory ingredients, and many other minerals occur occasionally, either disseminated in the mass or in veins. Colour, which depends materially on the colour of the felspar, is either greyish or reddish.

Granite, porphyritic.—Crystals of felspar in a small-grained granite. It is occasionally difficult to separate this rock from some varieties of protogyne.

Granites are divided by joints or planes of cleavage into irregular polyhedral masses. The metals which occur, either

disseminated or in veins, are principally tin, uranium, gold, silver and its sulphuret, oxydulous iron, bismuth, &c.

Protogyne, green.—Felspar, grey and red,—talc or chlorite of a deep green: green is the predominant colour.

Protogyne, red.—Felspar, grey or red,—talc and steatite, reddish brown or green, the red prevailing.

Such may be considered the characteristic or peculiar mineral components of protogynes; but M. Delesse has shown that they generally contain five minerals,—namely, a felspar in which potash abounds, a felspar in which soda prevails, a mica of magnesia and potash base, a variety of talc, quartz.

These rocks are bedded on a grand scale more decidedly than granites, and form the highest peaks of the Alps.

Syenite.—Felspar, quartz, hornblende; the felspar lamellar, and often predominating. This rock has been subdivided into sections, such as granitoid, where mica occurs in small quantity; porphyritic, where large crystals of felspar are imbedded in a small-grained syenite; zirconian, hypersthenic, diallagic, according as one or other of the minerals zircon, hypersthene, diallage, replaces in whole or in part either the hornblende or the quartz. Some of the varieties, particularly the schistoid, connect the granites with the greenstones, and some are so similar to metamorphic rocks as to make it doubtful whether they have a claim to be considered rocks of fusion.

Pegmatite.—Felspar and quartz; a silvery mica of potassic base is frequently present, as also tourmaline. The quartz is often arranged in broken lines, and produces that variety known as graphic granite, from the resemblance of the quartz lines to Hebrew characters. The felspar combines the two bases, potash and soda,—the former being to the latter in the proportion of 10 to 3 per cent. The quartz sometimes occurs in grains, and passes by the introduction of mica into granite or gneiss. Pegmatite is a variety of the granite group, very rich in silica, of which the proportion rises so high as 78 per cent. The finest kaolins, or porcelain clays, are produced by the decomposition of pegmatites.

SECOND GROUP

comprises another extensive family of rocks, of which greenstone is a type, the predominant constituent being hornblende.

Hornblende Rock.—Base, hornblende with mica, felspar, garnets, &c. Texture lamellar, and structure sometimes massive, sometimes fissile.

There are many varieties of this rock, such as the granitoid, the serpentine, the micaceous, the schistoid, &c., so named from the peculiar mineral or structure which prevails; and it is thus that the rock assumes by turns the true character of a plutonic rock, or those of the metamorphic series.

Greenstone (Diorite, &c.)—Hornblende and compact felspar, nearly equally disseminated. This rock is also subject to numerous variations, becoming granitoid, schistose, porphyritic, &c. The orbicular granite of Corsica is a greenstone in which spheroidal masses of hornblende and felspar occur in a paste of granular greenstone: a similar rock occurs in America, in which the spheroids are very small.

In the pyromeride, or orbicular porphyry of Corsica, radiated spheroids occur in a paste of compact felspar and quartz. Such forms are very interesting, as they are examples of concretionary structure, or of a tendency to definite arrangement within a mass.

The eurites, or felspar rocks and felspar porphyries, will be considered with volcanic rocks, though they sometimes approximate closely to the granitic type.

The next class includes the metamorphic rocks, which in many respects approach very closely to the plutonic. They exhibit a schistose and stratified character combined frequently with a highly crystalline structure. For a long time both granites and crystalline schists were considered primary rocks; and after the igneous theory of formation had been admitted for the massive rocks, it seemed difficult to separate from them a rock composed of felspar, quartz, and mica, and so highly

crystalline as gneiss. The alternation of gneiss with mica slate, granular limestone, and clay slate under all the forms of a definite stratification, rendered it, however, necessary to adopt some other and distinct theory of their formation. Had they even been homogeneous, or all similar in constitution to either granites or greenstones, they might have been ascribed to a similar origin, and considered portions of the original crust of the earth; but no such theory can account for the alternation of layers of limestone with gneiss or mica slate. The same reasoning therefore applies to these as to other stratified rocks; and they must be considered ancient sedimentary deposits, on which some peculiar change has been effected, which entirely masks their original condition; a change, which is signified by the expressive term metamorphous or metamorphic, and is, to a certain extent, not peculiar to such rocks, as many sandstones, conglomerates, and limestones have been altered, though not to the same extent, from the loose muddy paste in which they were originally deposited. The description naturally commences with the rock nearest in character to granite.

Gneiss.—Felspar, mica, and quartz,—the felspar lamellar, and the mica abundant, arranged in lines so as to produce a lamellar or schistose structure.

There are numerous varieties of this rock, as it is sometimes a distinct granite in texture, and sometimes merges into the next species, mica schist. It is occasionally talcose, approximating to protogyne,—sometimes is porphyritic, and occasionally loses its quartz,—whilst in a rare variety graphite in scales replaces the mica; and it may therefore be imagined how difficult it must be to draw a line of demarcation between some granitic and gneissose rocks.

Mica Schist (Glimmerschiefer of the Germans).—Mica predominates, and the structure is fissile. Garnets enter as an accessory constituent into this rock, as well as several other minerals. There are many varieties, as it becomes gneissose by the introduction of felspar, granitic by a more irregular

structure, porphyritic with a scaly fracture, or merges into a clay slate: it is sometimes talcose.

Clay Slate.—In this rock the distinction of crystalline elements is lost, but there are frequently accessory crystals of quartz, felspar, &c., by which it may be approximated to mica slate, just as that rock merges into it. It is sometimes so calcareous as to become almost a limestone slate, and the alternation of thin bands of limestone with the metamorphic rocks, especially with mica slate, is a remarkable and interesting fact, strongly elucidatory of their origin. Clay slate is also occasionally talcose, or becomes a talc slate.

The porphyritic character, which is common both to the igneous and metamorphic rocks, has been illustrated by the researches of modern Chemists, who have succeeded in retaining stony matter in fusion under such circumstances as should lead to the formation of crystals in the mass, on cooling. Various precious gems have thus been created in the laboratory; and to these experimental proofs of the manner in which the crystals of porphyries may have been formed, are to be added the researches of Person on alloys, which have shown that metals combined together in due proportions may first consolidate into a definite alloy, on arriving at a common solidifying point of temperature, and yet separate afterwards. The fact that such separation often takes place before consolidation,—the metals not arriving at a common point of solidification,—had before been noticed; and both facts, when extended to stony minerals, are highly explanatory of the porphyritic condition of rocks.

Some other less common rocks, such as serpentine, will be noticed hereafter in reference to their practical value: and the reader should observe generally, that, independent of any theory connected with them, massive and metamorphic rocks appear under several distinct forms common to them both; and as this fact is observable also in volcanic rocks, it is embodied in the accompanying Table, as a ready means to make the observer familiar with such rocks.

Massive Crystalline Rocks.		Stratified Crystalline Rocks, and more simple Strata connected with them.	
Granite	Felspar, quartz, mica.	Gneiss . . . . . Mica schist	Felspar, quartz, mica. Quartz and mica.
Pegmatite (graphic granite) . . .	Felspar, quartz.	Clay slate . . .	Crystals become so small that the mass appears homogeneous, though still glistening.
		. . . .	. . . .
Protogyne . . .	Felspar, quartz, talc.	Talc gneiss . . . . Talc slate	Felspar, quartz, talc. Quartz and talc.
Syenite	Felspar, quartz, hornblende.	Syenite schist . . .	Felspar, quartz, hornblende.
Greenstone . . .	Felspar, hornblende.	Greenstone schist . . Hornblende schist .	Hornblende, felspar. Principally hornblende.
Hypersthene rock .	Felspar, hypersthene.	Hypersthene schist .	Felspar, hypersthene.
Porphyry . . .	Granites, syenites, and other massive rocks exhibit frequently a porphyritic structure by the development of isolated crystals in the mass.	Hornstone porphyry Felspar porphyry . Clay porphyry . .	(The preceding rocks, including the various crystalline schists and many others, exhibit occasionally the porphyritic character.)
Ophite	Porphyritic serpentine or green porphyry.		
Dolerite (basaltic greenstone) . .	Felspar, augite. The crystals distinct, closely associated with ordinary basalt.	. . . .	Looking at the character of some of the beds associated with the basalt, it is scarcely possible to doubt that many of them are metamorphic, over which at various epochs the basalt has flown, and that similar changes have taken place in them as in other metamorphic strata. Using them as an illustration of the crystalline schists, it may also be suspected that streams of still more ancient lava exist in the close-grained greenstones associated in regular stratification with them.
Melaphyr, or augite porphyry . .	Felspar, augite. Rendered porphyritic by isolated crystals of both felspar and augite.	. . . .	This rock also indicates in part an original schistose arrangement.
Trachyte, or trapp porphyry . .	Felspar base, with crystals of glassy felspar; the ancient lava of Auvergne and of the Rhine.	. . . .	As yet I am not aware of any detailed account of truly metamorphic rocks connected with these.
Andesite . . .	So called from the Andes. The trachytes occur also in the basaltic district of Ireland, so that these two forms of lava are associated together just as the most recent lavas and basalt are.		
Domite	More earthy trachyte.		
Basalt	Felspar, augite. The mixture so intimate that the separate crystals can scarcely be distinguished: a distinctly volcanic product, still occurring in recent lavas.		
Lava, modern .	Including basalts similar to those of more ancient volcanoes.		
Leucite lava . .	Leucite and augite—the former prevailing; this mixture being also rendered porphyritic by isolated crystals of augite and glassy felspar.		

Before describing truly volcanic rocks, the connection of plutonic and metamorphic rocks with the leading physical phenomena of the universe requires consideration. An hypothesis has been advanced in Astronomy, that the now solid planetary bodies were once in a state of gaseous fusion as nebulous matter, and were gradually condensed into their present state. The figure of the earth, which is an oblate spheroid, has been appealed to in support of this theory, as a liquid body subjected to the conjoint action of gravity and a rotatory projecting impulse would assume such a form. The figure of Jupiter is also consistent with the theory, but that of Mars appears as yet opposed to it. If, then, the earth has passed through a fluid state, the cause of such fluidity appears closely connected with heat, as an examination of the temperature of the earth's crust at various depths shows that the temperature below the cooled surface increases on descending, and that at great depths there is still existing a vast reservoir of internal heat. From numerous observations made in mines and by Artesian wells in France, England, Prussia, Russia, and elsewhere, Leonhard states that the temperature increases by 1° Reaumur, or $2\frac{1}{4}$° Fahrenheit, in 120 feet. M. Reich considers the temperature in the mines of Saxony to increase 1° centigrade in 41·84 m. of depth, or $1\frac{4}{5}$° Fahrenheit, in 135 feet. In a boring in the Military School at Paris, the increase was found to be 1° centigrade, or $1\frac{4}{5}$° Fahrenheit, for about 96 feet. In Mr. Fox's experiments in Cornwall, the increase was found to be about 1° in 47′: in those of Mr. Oldham, in the copper mines of Knockmahon, county of Waterford, 1° in 82′, being a lower rate of increase than that of previous inquirers. It may be therefore assumed as a reasonable approximation, though subject to many variations from the different conducting powers of different strata, that the temperature increases 1° Fahrenheit in 60 feet of depth; and if the rate of increase were considered constant, there would, at 60,000 feet, be a temperature of 1000° or that of low red heat; but as the temperature will increase with the

depth in an augmenting ratio, Leonhard assumes that this temperature would be attained at about 35,000 feet, being a depth only double the height of Cotopaxi, the most remarkable of the Peruvian volcanoes. Descending still lower, the temperature, at a very moderate depth compared with the magnitude of the earth, would be found sufficient to retain mineral matter in a state of fusion; and it is therefore unnecessary to place at a great depth the source of the lava which is still pouring out in so many parts of the earth. The similarity of lava, wherever found, and the close agreement as to composition and physical characters of the basalt of ancient epochs and of that still bursting through and intersecting the walls of modern volcanoes, are further proofs that all such eruptions have a common origin, and are due, as well as the accompanying physical phenomena of earthquakes, to forces acting on the still liquid portion of the earth.

If then the original igneous fluidity of the earth, and its gradual cooling from the crust downwards, be admitted, it has been demonstrated by Fourier—

1. That the cooling of the earth, and the increase of temperature in proportion to the depth below the surface, has been much greater formerly than it now is.

2. That more than 30,000 years will be required to lessen, by one-half, the present rate of increase of temperature; that is, to reduce the increase to $\frac{1}{2}°$ in 60 feet.

3. That the effect of central heat is now scarcely perceptible on the surface, not raising the thermometer $\frac{1}{17}°$.

4. That for nearly 2000 years this effect has not diminished by $\frac{1}{70}°$, and that in this, as in all the great phenomena of the universe, a marked character of stability is perceptible.

The density of the earth affords another means of judging of its internal condition. It has been stated that the density of the crust lies between 2·7 and 2·9; but the density of the whole earth, derived from pendulum experiments, of which more will be said when treating of elevatory forces, is about 5·5; so that it is evident that the ponderable matter of the

interior of the earth is very much denser than the matter of the crust, which is quite consistent with the previous supposition of original fluidity; for though gases mutually permeate each other and diffuse themselves, liquids, when they do not exercise a chemical action on each other, obey the ordinary laws of gravity, and arrange themselves in the order of their density. The density of basalt does not usually exceed 3·1, so that the difference observable by the Geologist in the densities of rocks is very small. The radius of the earth is 3908 miles; but if we suppose it 4000 miles, and divide it into 10 equal parts, and then assume that in descending the density increases in an arithmetical progression by about 1·5 for each part, the problem will be thus stated: the average density in the first annular space of 400 miles will be 2·7; in the second 4·2, and so on,—the density of the last 400 miles being about 16·2; a view of the case which does not appear inconsistent with facts, as it allows an increase in density of ·3 for 100 miles, which is probably more than the thickness of consolidated strata.

The increasing density of the earth, from the surface to the centre, has an important bearing on the nature of plutonic rocks. The density of none of the true granites equals that of basalt, and it rarely exceeds 2·6, so that it is highly improbable that granite has proceeded from a deep-seated source. Granite does not throw out dykes either cutting through the strata or filling up cracks produced by fracture in them; its veins are principally confined to the metamorphic rocks, and it does not exhibit lava currents: it may therefore be considered a lower portion of the immediate crust of the earth which has been liquefied and forced to the surface at various epochs, but has not been erupted. The full development of crystals in these rocks requires slow cooling but not great pressure, and there is therefore no reason for supposing that they were ever far below the surface.

In extending the inquiry to the crystalline schists, it will be

naturally asked whether any portion of them may be considered a part of the crust of the earth as it was at first cooled down and consolidated. The alternation of limestone and of micaceous beds with the more crystalline schists confines this question within very narrow limits, and if any rocks now visible can be supposed not to have passed through the sedimentary stage, they are probably only such rocks as the highly inclined and distinctly bedded varieties of protogyne which occur in the Alps,—being neither distinctly massive nor distinctly stratified. There is a similar difficulty in determining whether the hornblendic rocks associated with the crystalline schists are metamorphic or volcanic rocks. Their density being nearly equal to that of basalts, assimilates them to erupted rocks; and modern Geologists have discovered so strong a resemblance between some of the strata associated with the crystalline schists and the ashes, lapilli, &c. of volcanoes, as to strengthen the belief that lava currents have been instrumental in the production of some metamorphic strata. This portion, therefore, of the Earth's Mineral History is a fitting introduction to the next, in which the products of volcanic eruptions are recognized by their similarity to and even identity with the mineral matter erupted from volcanoes either now existing or which have existed since the earth's surface assumed its present form, though now extinct.

The truly volcanic rocks have been divided into three sections,—trachytic, basaltic, and lavic, the last of which are now observed amongst volcanic erupted substances whilst dykes of basalt penetrate the walls of volcanic cones.

The trachytes are felspathic rocks, consisting of a highly crystalline paste of compact felspar, with crystals of augite and other minerals disseminated in the mass. Domite, porphyritic eurite, pumite, phonolite or clinkstone, belong to the division; and there is a trachytic breccia to the production of which mechanical action has contributed. Trachytes occur in countries where volcanoes are still in action as well

as in those where they have become extinct, and they appear to have proceeded from a source immediately below the granitic crust. The chain of the Caucasus, Hungary, Transylvania, Auvergne, Isles of Greece, Italy, &c., and the counties of Antrim and Down in Ireland, are good localities. Trachyte, as Andesite, acquires an enormous development in South America, in the chain of the Andes of which it forms the summits, the beds being sometimes 14,000 or even 18,000 feet thick, as at Chimborazo and the volcano Guagua-Pichincha, and it is also observed in the volcanic districts of New Zealand. Trachytes are sometimes covered by tertiary strata, but never by the secondary or older strata, and it has therefore been assumed that the epoch of their first appearance is that of the earlier tertiaries. In Auvergne they often form the boundaries of ancient and partially destroyed volcanic vents; and it is not improbable that in like manner the Antrim and Down trachytes are portions of the boundary of some great volcanic vent, which occupied the site of the present Lough Neagh, and through which much of the basalt of the district may have been poured out.

Basaltic rocks, in which augite predominates in quantity over felspar, are augitic rather than felspathic rocks, and some of the varieties which are highly crystalline like greenstone can scarcely be distinguished from that rock. Basalt has a considerable density, ranging to 3·3 in the more highly augitic varieties; it cuts through granite and every successive rock, carrying with it and enveloping fragments of the rocks broken through. The remarkable lines of this igneous matter, which may be sometimes traced for very long distances, are called dykes, and, when exposed by the decomposition of the softer strata through which they have passed, stand out as walls, from which circumstance they have derived that name. See fig. 15, which is the celebrated dyke called Lady O'Cane's Bridge, and fig. 16, which represents another view of it.

Fig. 15.—East View.

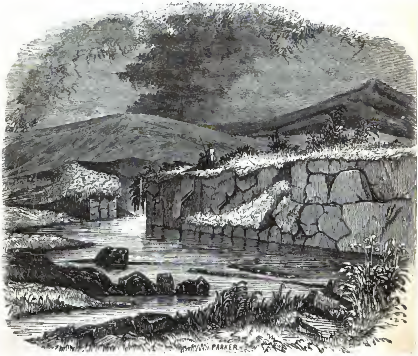


Fig. 16.—West View.

Basalt having cut through granite, must have come from below it and the metamorphic schists, though there is no reason for supposing the depth of its source more than 100 miles. Basalt is rarely found near the summits of volcanoes, but usually at their base or surrounding them, and is anterior to the lava currents which overlie it: it is very extensively developed in the vicinity of extinct volcanoes, and is justly considered a truly volcanic rock. In many countries, as in Ireland and Scotland, it is spread out in extensive plains or beds, which are divided in section or depth into many successive layers, the structure of which is sometimes globular and sometimes columnar, as at Staffa and the Giant's Causeway, and which alternate with beds of ochre or ferruginous scoria, as well as with beds which have probably been originally sedimentary, and are therefore metamorphic. Sometimes, as in the vicinity of Jorullo, in Mexico, the basalt has been puffed up by the elastic gases below into small cones or bosses, which, having been subsequently cracked, emit aqueous and sulphurous vapours. These Hornitos, as they are called, cover in thousands the great plain of Mal-Pais, in which Jorullo rises, so that the surface resembles the bubbles on the top of a boiling viscous fluid. In 1780 the heat of the hornitos was so great that a cigar could be lighted by plunging it 2 or 3 inches into one of the lateral cracks. By the layers of ochreous scoria the mass of basalt is divided into successive flows, some of which either passed over the dried and consolidated ochreous mud, or over the mud still under water where it had been formed by showers of ashes; and the connection of irregular or orbicularly crystallized basalt with columnar, the former capping the latter, is the result of the more rapid flowing and cooling of the upper portion. A beautiful example of this effect is exhibited at Craignahulliar, in the county of Antrim. See fig. 17, in next page.

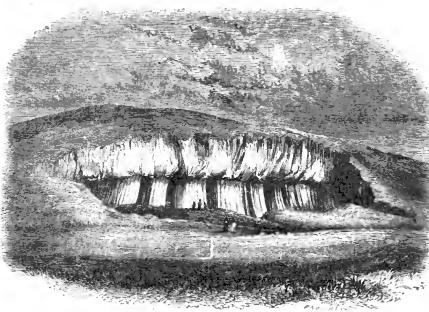


Fig. 17.

The lavic division can be studied in the phenomena of still active volcanoes. True lavas have been erupted subsequently to the basalts: the lava of extinct volcanoes approaches more closely to trachytes, being felspathic, whereas that of existing volcanoes, being augitic, is nearer to basalts. Successive flows of lava are frequently separated by beds of ashes, scoria, lapilli, &c., as may be seen in the vicinity of Vesuvius. The eruption, supposed to be the first of Vesuvius, which in the year 79 destroyed the cities of Herculaneum, Pompeii, and Stabiæ, and caused the death of the elder Pliny, consisted of ashes. It is impossible, in this small volume, to describe all the phenomena of volcanoes; but the great number actually recorded is shown by the following approximative Table from Girardin. And as the number of extinct volcanoes has also been very great, the eruptive forces of former and of existing epochs were equal in intensity if estimated by the quantity of matter erupted.

Portions of the Earth.	On Continents.	In Islands.	Total.
Europe . . .	4	20	24
Africa . . .	2	9	11
Asia	17	29	46
America . . .	86	28	114
Oceania . . .	„	108	108
Total	109	194	303

Peculiarities of some of the igneous rocks, and the effects of igneous, and especially of eruptive rocks, on the earth's crust; many of these rocks having been important agents in the successive disturbances of the earth's surface.

The wide extension of the granite group over the surface of the globe must be referred to general and not mere local forces; and the frequent co-existence of granite and metamorphic rocks proves that the causes which produced them were intimately connected together. In the Erzgebirge at Geier the granite has forced itself up, in three blunt hills, through the mica schist, which in its vicinity has been further changed into gneiss; and in the county of Cavan, in a similar manner, rounded hills of granite occur amidst an ancient metamorphic schist. In the former case, the granite has evidently been protruded subsequent to the deposition, and even to the partial metamorphism of the schists, though the exact epoch of protrusion is not determinable. In the granite of the valley of the Neckar, near Heidelberg, though the exact age cannot be settled, it is limited upwards, as the new red sandstone, now partially removed by denudation, once covered the granite, and was therefore deposited subsequently to it; and such examples prove repeated action of elevating forces, by which the surface of the earth was disturbed and igneous rocks protruded at various epochs. — Granite forms either mountain masses, or veins. The veins are of various thicknesses, from a few inches to several feet, and massive granite is frequently penetrated by veins of granite of a different character, so that Leonhard designates the one, which is rendered porphyritic by disseminated felspathic crystals, moun-

tain granite; and the other, which is not porphyritic, vein granite. When granite contains hornblende, it passes into syenite, and by the passage of syenite into greenstone a connection is established between ancient and modern eruptive rocks. In the Odenwalder, syenite is traversed by many granite veins, but a vein of the syenite has not as yet been observed in the granite, so that it is assumed that the syenite is there older than the granite. Granulite or weisstein, in which compact felspar is the principal constituent, has a close analogy to trachytes or felspathic lavas; it sometimes assumes an independent massive form, and its veins traverse granite. Veins of granite, granulite, and syenite often contain large fragments of gneiss and other schistose rocks, which in the vicinity of the masses from which the veins have proceeded are both much contorted and greatly metamorphosed. At Meissen and Hohnstein, in Saxony, granite overlies the quadersandstein, a result, it is supposed, of disturbance: at Christiania in Norway, and in the Hartz, it is found between the layers of primary schist and limestone, into which it has penetrated by veins, changing the schists into a species of hornstone; and many such examples might be cited from similar districts. Greenstone, though it approximates to granite by the intervention of syenite, is closely allied to basalt, and forms therefore a connecting link between the two groups; but whilst granite and syenite afford only very obscure examples of intercalation with or superposition to stratified deposits, greenstone is often so closely connected with both the non-fossiliferous crystalline schists and the primary fossiliferous schists, occurring not only in intruded masses and penetrating veins but also in beds alternating with the regular strata, that Werner classed it with them. Schistose beds penetrated by greenstone are often contorted in a similar manner as by the action of decided igneous rocks; and where the greenstone and schists are disposed in regular and parallel strata, a distinct transition from one to the other can frequently be observed, though in some instances, especially where there is a thick bed of limestone, the separation between

the two is very distinctly marked. It is thus that the more decided metamorphic theorists consider greenstone an ultimate result of metamorphism, whilst the eruptive theorists connect it with erupted rocks, and look upon its alternating beds as the products of so many distinct eruptions. In the neighbourhood of Schwarzenberg the mica schist is penetrated by layers of greenstone more or less parallel to the stratification; and as fragments of the adjacent rocks have been taken up by the greenstone, it has been suggested that the igneous matter has been forced into fissures corresponding with the natural lines of lamination of the strata. Some of these conformable dykes are more than 30 feet thick. This locality is rich in ores, especially magnetic pyrites, iron pyrites, arsenical pyrites, tin ore, black and brown blende, lead glance, and silver, and in simple minerals,—namely, garnets, vesuvian, chlorite, epidote, tourmaline, prase, mica, calcareous and brown spar, and many others, the original composition of the rock being almost concealed by the ore it contains. Granular limestone and dolomite are connected with the greenstone here as in other localities.

Greenstone is characterized by knoll-like or conical masses, which are sometimes recognized at a distance as small lump-like excrescences projecting above the stratified deposit, and a columnar structure, though rare, is occasionally observed. The close resemblance between syenite and greenstone makes it desirable to have some rules for distinguishing them: Cotta gives the following—

Syenite.	*Diorite, Grünstein or Greenstone.*
The dark green hornblende, blended with the yellowish or red Labrador felspar and weathering nearly together, both form on the surface an iron-shot crust.	The mostly white albite weathers sooner than the dark green hornblende, so that the crystals of the latter project above the weathered surface.
Colour.—Reddish or whitish green.	Green, approaching to black.
Occasional Ingredients.—Almost constantly small brown crystals of titanite, and sometimes quartz and mica.	Iron pyrites and magnetic pyrites (simple sulphuret of iron).
Fissures, lined with epidote.	Also common.
Forms.—Massive and angular, and stitute mountain masses.	Conical: knolls, masses, small masses, layers, or veins.

Serpentine is allied to greenstone, and exhibits similar physical features. Its veins penetrate the crystalline schists, as well as granitic rocks, and it appears to have been protruded amongst the beds of the Jura formation, being abundant in the Alps. The well-known mixture of serpentine veins in marble is a curious example of metamorphic action, as it indicates diffusion rather than penetration, the veins having no connection with any great mass. The fissures and cavities of serpentine are often covered with asbestus. *Porphyry Group*, including felspar porphyry, pitchstone porphyry, and augite porphyry: rocks which all affect a similar physical character, appearing in lump-like masses and in dykes projecting into granite, crystalline schists, and various stratified deposits. They frequently appear as isolated hills amongst other rocks, and have been noticed in all parts of the earth. Felspar porphyry, including hornstone and claystone porphyry, forms extensive masses, and also dykes of great length, which frequently contain fragments of the rocks passed through, and are sometimes bounded by a breccia formed by their attrition against them. The pervading form of this group of porphyries is rather angular than round, and as tabular beds and columns are common, there is much analogy in structure to basalts. Metallic veins are rare in the porphyry, though more frequent at its contact with schists. A remarkable example of these rocks is seen in the Tharander Walde, where several powerful dykes proceed in tangents rather than in radii, from a round knoll more than a mile in diameter. The main mass lies between gneiss and clay slate, and its dykes ramify through both. At the Zeisigsteines it becomes columnar and at the Esberge still more so, the overlying rock being quadersandstein. Between Freiberg and Frauenstein, dykes many miles long cut through gneiss, and are themselves penetrated by metallic veins. *Pitchstone porphyry*, including pitchstone and pearlstone, is comparatively rare, and is usually connected with other porphyries, which it either penetrates in mass or by dykes: it occurs in Saxony, in Hungary, and ex-

tensively in the island of Arran: it appears also in the felspar porphyry district of Antrim. *Melaphyr* (*augite porphyry, augite rock, &c.*) is sometimes amygdaloidal, and generally forms small knoll-like masses, or irregular dykes which penetrate massive and schistose rocks and effect important changes in the fossiliferous deposits. There are many varieties of this rock, and it becomes porphyritic from detached crystals of augite, of mica, or of felspar. By its bladder-like and amygdaloidal structure, and the occasional appearance of columns, it approximates to basalts, and it has been rendered remarkable by being in juxtaposition with masses of magnesian limestone or dolomite, which Von Buch supposed to have been produced by a contemporaneous emanation from the interior of the earth of magnesian vapours and their action on pre-existing limestone. *The Basalt Group* brings up the working of ancient igneous forces to the very threshold of the existing epoch. In basaltic countries, isolated conical hills are common, and knob-like masses of all sizes and heights project above the surface of the country, being sometimes connected together in one great mass. Basalt is either spread over other strata, like a stream of lava, or alternates with them, having penetrated through both the ancient igneous rocks and all the fossiliferous strata up to the post-tertiary, some varieties intersecting others of more ancient date. Where basaltic dykes have crossed other rocks, remarkable chemical and mechanical effects have been produced: granite, gneiss and mica schist have been reddened, and (especially the mica) partially melted; clay slate burnt and hardened; sandstone reddened, glazed, and reduced to a columnar structure; stone and wood coal, charred; limestone sometimes deprived of its carbonic acid, and frequently reduced from an earthy or compact to a crystalline state; shale changed to jasper; fragments of underlying beds raised to a higher level, and the regular strata disturbed and uplifted, though not to the same degree as by granite and porphyry, the chemical exceeding the mechanical effects in this class

of rock. *Phonolite* (clinkstone and clinkstone porphyry) is not so widely spread as basalt. Passages between clinkstone and trachyte may be traced, and, where this rock occurs in masses, the larger generally possess more of the trachytic, and the smaller of the phonolitic character. Columnar and tabular forms of structure are observable as well as dome-shaped or conical hills. The trachytes which occur in the well-known Siebengebirge, in Hungary, in the South of France, and in the Andes, pass occasionally into phonolite, and on the other hand varieties of phonolite are found associated with basalt. *Lava* in its basaltic, greenstone-like, trachytic, porphyritic, leucitic, and slag-like varieties, exhibits a close analogy to other erupted rocks of all epochs.

Volcanoes and Earthquakes.—In order to comprehend the influence of volcanoes, which are the foci of eruption, as a modifying geological force, it is necessary to bear in mind that they are intimately connected with earthquakes,—the earthquake often preceding the volcanic eruption, and both being the result of the movement of matter in the interior of the earth. It is thus that whilst the lava which now flows in streams over the sides of the crater, and the dykes which penetrate its walls, are illustrations of the more ancient igneous products, the movement of the earth's crust, its upheaval or its depression, and the cracks which fissure it under the action of earthquakes, or earth-waves, are equally illustrative of the mechanical effects of former forces of a similar nature.

In the great earthquake of Chili, 19th of November, 1822, the shock was felt along the coast for 240 miles, and by many natural appearances, such as the exposure of beds of shells at times of the tide when they were not before so exposed, it was ascertained that at Valparaiso the uplifting amounted to three, and at Quintero to four feet; and as the great chain or axis of disturbance along which the volcanoes are arranged is at a considerable distance, it is reasonable to suppose that all the intervening country was similarly raised. There are traces of more ancient shocks which have raised the coast

about 50 feet. In the rocks of the coast which are granite and syenite, there are numerous parallel cracks which can be followed landward for 1½ mile. The effects of this earthquake extended over a space of 100,000 square miles. An earthquake shook violently part of Wallachia on the 11th January, 1838; many parallel fissures were formed, and then filled by matter forced upwards. The earthquake which destroyed Lisbon, 1st November, 1755, was felt throughout Europe so far as Norway, on the north coast of Africa, in several of the West India Islands, and by many ships at sea. At Lisbon, an adjacent hill was split in two, and the new quay sunk 600 feet below the water. The changes of level of the celebrated Temple of Puzzuoli, near Naples,—the rising and sinking of the land in Scandinavia,—the sudden appearance of islands forced up from below,—are all phenomena which exhibit the still continuing action of elevating forces. Jorullo, in Mexico, is an example of volcanic action combined with extensive elevation, and Skaptaar Jokul, in Iceland, poured out a stream of lava which may vie with many of the ancient basaltic streams—being about 50 miles long, 12 miles wide, and on an average 100 feet thick.

The contemplation of such wonderful effects of still acting causes prepares us to estimate forces which acted according to the same laws in former epochs. Whilst, therefore, water has worn down, transported, and re-deposited mineral matter in nearly regular and horizontal order, or, in other words, restored the level of the earth's surface, that level has been disturbed by the action of internal forces, which have elevated some portions of the surface above others. Elevation of the earth's crust is necessarily accompanied by contortions and by cracks varying according to peculiar circumstances: where, for example, the elevating force acts on a point or small space, an isolated mass or mountain may be formed with cracks radiating from a centre; or should the superficial pressure be diminished, the crust may be raised like a great bubble, and, finally separating at its apex, form the circular wall of what Von

Buch calls a crater of elevation: if it acts on the line of a crack, either one side may be uplifted so as to form a steep precipice overhanging a plain (an appearance not unusual in nature), or both sides forming two precipices, with a valley of elevation between them; and again, if upheaval takes place where one set of cracks crosses others, there will be various modifications of the primary ridges. Such forces, continuing to act at intervals for ages, have produced the great and the cross chains of mountains. Von Buch, pursuing these inquiries, observed that in certain districts the mountain chains, the strike of the strata, and even the great valleys, had certain predominant directions; and Elie de Beaumont, extending Von Buch's researches, founded upon them, in 1830, his Theory of Elevation, according to which *all mountain chains of the same age have the same general direction.* His Theory, as now modified, may be thus stated; that the earth's crust has been elevated into mountains at various periods by forces acting in the direction of great circles of the sphere; and to determine the relative ages of such upheavals, he assumes that uplifted and highly inclined strata were deposited prior to the upheaval which disturbed them, and that horizontal strata which overlie the inclined or disturbed must have been deposited subsequently to such upheaval; and hence that the epoch of elevation may be determined by the relations of successive sedimentary deposits to each other. M. Elie de Beaumont at first distinguished about fifteen systems of elevation, of which the twelve following are the most remarkable.

1. *System of Westmoreland and Hunsdrück.*—Direction of elevation, N. E. $\frac{1}{4}$ E. and S. W. $\frac{1}{4}$ W. No newer strata than the Silurian, and probably a part of Devonian, uplifted. This includes the Eifel, the Taunus, the Isle of Man, and South Shetland. 2. *System of part of the Vosges.*—Direction, E. 15° S., W. 15° N. Mountain limestone, but not the coal-bearing strata, uplifted. To this belong the hills of Bocage, in Calvados. 3. *System of the North of England.*—Direction, S.—N. The coal-bearing strata are the most recent affected

in this elevation. 4. *System of the Netherlands and of South Wales.*—Direction, N. E.—S. W. The whole of the coal formation affected. 5. *System of the Rhine.*—Direction, S.—N. or S. S. W.—N. N. E. Strata to the Zechstein (magnesian limestone) uplifted. The Vosges, Schwarswald. 6. *System of Bohemian and Thuringian Forests.*—Direction, S. E.—N. W. The keuper is the newest formation disturbed. La Vendée, Bretagne. 7. *System of the Erzgebirges.*—Direction, S. W.—N. E. The oolite or Jura, but not the quadersandstein, affected. Côte d'Or, Mount Pilas and the Jura in part. 8. *System of Monte Viso.*—Direction, N. N. W.—S. S. E. The older but not the newer chalk affected. 9. *System of the Pyrenees and Apennines.*—Direction, N. W.—S. E. The younger or upper chalk, but not the tertiary strata, affected. This system being parallel to No. 6, it is often difficult to separate one from the other. Hartz, Teutoburger Forest, &c. 10. *System of Corsica and Sardinia.*—Direction, S.—N. The lower tertiaries, but not the upper, affected. The basalt of Hesse. 11. *System of the Western Alps.*—Direction, N. 26° E.—S. 26° W. The newer tertiaries affected. 12. *System of the main chain of the Alps: from Wales to Austria.*—Direction, W.—E. or E. N. E.—W. S. W. A portion of the post-tertiaries affected. Monte Ventoux, Leberon.

M. Elie de Beaumont has since extended his determination to at least twenty-one systems of mountains, the relative ages of which have been determined with more or less precision,—namely, the systems of La Vendée, of Finistère, of Longmynd, of Morbihan, of Hundsrück, of the Ballons, of Forez, of the North of England, of the Low Countries, of the Rhine, of Thüringerwald, of the Côte d'Or, of Monte Viso, of the Pyrenees, of Tatra, of Sancerrois, of the Western Alps, of the main chain of the Alps, of Tenare and of Vercors; and M. Durocher has pointed out several other systems in Scandinavia. The difficulty in determining the actual connection of a chain of mountains with some definite system is sometimes great, as disturbances and elevations frequently occur in the same dis-

trict and nearly in the same direction. This periodic recurrence of pulsations, as it were, of the earth's crust in particular districts, rather than indefinitely over the whole surface, has led M. de Beaumont to inquire whether the various systems of mountains resulting from the action of some central force, and therefore necessarily exhibited in great circles on the surface, may not be reduced to some geometric law; and the result of his investigation is, that the phenomena may be best exhibited by dividing the surface of the sphere or earth into twelve regular spherical pentagons produced by the intersections of fifteen great circles. The various systems of mountains may then be arranged around the angles of the pentagons, and be considered as produced by disturbances acting in auxiliary great circles passing through the angles of the pentagon and forming so many bulging or even geometric projections (like the boss of a shield) of which the angles of the primary pentagons are the apices.

Whatever opinion may be formed of the details of M. Brongniart's theories, in their groundwork they are correct, and they have had and will have a most powerful effect on the progress of geological science.

The fact has thus been established, that at successive epochs the earth's crust has been broken up and elevated, whilst various igneous rocks, the most superficial of which was probably granite, were lifted up and forced into the cracks of the disturbed crust; but the mode in which the great elevating force has been developed has yet to be investigated, and here indeed is a difficulty, as direct observation can only extend to a mere film of that earth the surface of which it has affected in so striking a manner. The facts, however, of disturbance are palpable, and the nature even of the forces producing them can be inferred, though not demonstrated by observation. Electricity may be fairly classed with these forces, if only as a secondary cause; and it may be affirmed on sufficient reasons that heat was a primary one. In 1837 Gustav Bischoff assumed a fluid condition of the central portions of the earth

from heat, and from physical considerations deduced that hot springs, the production of massive rocks from the cooling of the fluid mineral matter, volcanic eruptions and earthquakes consequent on the expansive force of steam produced by contact of water with the still heated and fluid internal mass, were the results of such a condition.

Sir H. Davy proposed a chemical theory of earthquakes, founded on the properties of the newly discovered bases of the alkalis and earths. These bodies, when brought in contact with air and water, are oxydated with great rapidity, producing an intense ignition: he therefore considered it probable that potassium, sodium, calcium, &c. exist in great quantity in the interior of the earth, and coming into contact with water which had penetrated by cracks or filtration, is suddenly ignited and oxydated, giving rise to volcanic fires and to the formation of various stony compounds, which, as lavas, are then erupted. The great quantity of sodium in combination with chlorine, iodine, and bromine in sea water and in salt deposits indicates that this cause must not be entirely rejected in accounting for local phenomena, though it is insufficient to account for the more general phenomena of disturbance.

The theory of Cordier is purely thermometrical, and is very generally adopted by Geologists: it may be expressed under the following heads:

1. The earth has an internal temperature, which is independent of the solar heat, and increases rapidly with the depth.

2. The rate of augmentation is different at different places; in one country it may be double that of another, and the difference is *not* in a constant ratio with either latitude or longitude.

3. As the total mass of the earth is about 10,000 times greater than that of the waters connected with it, it is more probable that the original fluidity of the earth was due to heat than to aqueous solution. The heat was very great, as the present temperature at the centre of the earth, supposing a

regular progression in the increase downwards, exceeds 3500 of Wedgewood's pyrometer = 450,000° Fahrenheit.

4. A temperature of upwards of 12,000° Fahrenheit, which is sufficient to melt most of the known rocks, would exist at depths below the surface varying from 80 to 160 miles, supposing the increase to be regularly progressive; but it is highly probable that the dense fluid portions of the earth are much better conductors of heat than the crust, and therefore that this high melting temperature is acquired, and that the actual fluid portion commences at a still less depth.

5. As the crust of the earth, leaving out of consideration sedimentary deposits, has been consolidated by cooling, its formation must have taken place from without inwards, so that the more superficial crystalline rocks are the most ancient; and this accords well with the small density of granite which appears to have been uplifted under so small a comparative pressure as not to have been actually erupted. The thickness of the crust will continue to increase until the cooling has attained its final limits.

6. There is no reason for believing that the solid crust can be more than from 60 to 100 miles thick, and it is probably much less: that it is very unequal, is shown by the variation of internal temperature, which cannot be explained by different conductibility alone. It possesses some degree of flexibility, and the phenomena of earthquakes are due to the expansive force and consequent pressure which the fluid nucleus within exercises upon it.

7. The solid crust continues to contract as its temperature diminishes in a greater ratio than the central mass; and as the velocity of rotation must increase as the diameter of the planet diminishes, there will be a tendency to diverge further from the spherical form, and hence the fluid matter within will press against the contracting crust, and produce volcanic eruptions. M. Cordier has calculated that a contraction of $\frac{1}{12350}$ of an inch in the mean radius of the earth would be sufficient to force out the matter of a volcanic eruption.

In this hypothesis, the zones of least thickness of the earth must be the sites of volcanoes. Professor Rogers, of Philadelphia, has traced the progress of three great earthquakes in the United States, the synchronous lines of which, or lines along which the shock was felt at the same moment, extended 300 miles in a direction from N. E. to S. W., the progressive motion being to the eastward, at the rate of 30 miles a minute. It is highly probable that electric forces called into action by change of temperature have aided in the production of these effects, and that partial differences in the conductibility of different strata have increased or diminished the intensity of earthquake shocks or waves, and by producing local cracks have been one of the causes of the various subterranean noises which accompany these great and fearful phenomena.

It may be added that M. Rozet, by comparing a series of pendulum experiments with the geodetic measurements in France and with barometric observations, has proved that lofty mountain chains are not the only evidences of the disturbance of the crust, but on the contrary, that the apparently level surface of the earth conceals many undulations which, by their effects on the pendulum, have evidently been produced by the swelling up of denser matter within them. M. Rozet has further established the fact that the ocean has not, as so many English Geologists imagine, an invariable level, but participates in the movements, and conforms itself to the varying level of the solid crust. "We find," he says, "that the true level of the ocean is below the mean elliptic level in the Polar Sea, on the coasts of Spitzbergen and Greenland, as also on the coasts of Great Britain, at the Equator, and in the Southern Ocean, and that it is above that level on the coasts of Norway and at the Cape of Good Hope." This inequality of absolute level in the ocean, consequent on the protuberances and hollows of the crust of the earth, must have varied with, and been in proportion to, every great disturbance, or to the amount of matter protruded above the mean elliptical level of the liquid nucleus. By the calculations of M. Rozet, the mass

of the Alps, if entirely composed of basalt, should deflect the plumb-line only 13″·5, whereas on the eastern flank of these mountains the deflection amounts to 28″, and on Mount Cenis itself to 8″·5; whence it is concluded that this great deflection is due not merely to the mountain itself, but to the denser matter proceeding from the interior of the earth, which had been forced into the protuberance, on the summit of which the mountain chain rests. It is not therefore the sedimentary deposits alone which have acquired an irregularity of surface; the general form of the earth has been altered from its original condition, not by one but by many successive commotions, and as the thickness of the solidified crust has continued to increase, the most recent chains of mountains are necessarily the most elevated.

The violent intrusion of igneous matter either into cracks of the crystalline portion of the earth's crust or amongst the more purely sedimentary strata must tend to crush, consolidate, and contort the strata, and, wherever the crust has been rent asunder, to produce a jar or vibration of the solid matter, which jar is transmitted like the vibrations of sound through the solid crust, and constitutes an earth-quake or wave. This theory of Young and Gay Lussac has been lately most admirably worked out by Mr. Mallett in his Reports to the British Association. It is highly probable that in some cases the igneous matter injected from below and the wave of the solid matter has only affected the lower strata, which have been contorted, whilst the beds above them have remained apparently unaffected by the disturbance. In such cases there would be an apparent but not a real want of conformability. In other cases igneous matter may be forced to the surface, as in volcanoes, and comparatively little jar or earthquake produced. In the theory of Cordier, the central nucleus of the earth is considered a liquid of ignition, but it has been urged that the great pressure would retain it in a solid state: if, however, such be the case, wherever the pressure was relieved the matter would become locally liquid, and thus agree with

the opinion of Mr. Hopkins, that there is not a universal central sea of molten mineral matter, but local lakes from which volcanic vents are supplied. These two theories are therefore reducible to one. To the probable influence of electricity should also be added that of magnetism, as the beautiful discoveries of Mr. Faraday have made it easy to connect it with great physical phenomena. All bodies are either paramagnetic or diamagnetic, that is, they are either in a state of magnetic attraction or of repulsion: if, therefore, a change in these conditions be brought about by any agency, whether it be heat or electricity, the cohesion of matter will suddenly cease in one place and at another be called into action, giving rise to violent disturbances even in the solid matter of the earth.

Practical Applications.—The practical importance of metamorphic, plutonic, and volcanic rocks requires a brief notice. *The metamorphic* includes those varieties of clay slate which are used as roofing slates; and the physical condition of the strata is therefore a guide in searching for slates, as their peculiarities and value are due to metamorphic action. The lesser cleavage of the slate is usually transverse to the dip of the beds; and the probable value of the slaty beds may be estimated by the presence or absence of this character, as the planes of separation by cleavage are more regular, and possess a more even surface than those of stratification. For flagging, many crystalline schists are excellent, as the surface of stratification is sufficiently even in the gneisose varieties of mica slate and in gneiss; and they also often furnish good rough building stones, affording a flat bedding and a very durable composition. In these three varieties of metamorphic schists the important physical character of specific gravity is nearly uniform, as it ranges in each from about 2·6 to 3·1, which is the specific gravity of the more dense or indurated varieties which are frequently hornblendic or greenstone schists. As road stones, the latter only should be used, as other varieties speedily break up and are reduced to mud. Roofing slates

ought to split thin and even, but should neither cleave into fragments nor break off in scales; they should not absorb much water, as it induces the growth of moss, which speedily disfigures them and produces damp. Though the dark grey varieties are most approved, the silver grey are usually the most durable. Some varieties of mica slate afford good roofing slates, which, however, are seldom so thin and even as the less crystalline schists. Wales is the most important locality of the United Kingdom, but there are very good slates in the South-west and in the South of Ireland, as at Killaloe on the Shannon, and in the island of Valentia, and some from the mica slate of the North of Ireland though they are inferior to the true slates. Of foreign localities, that of Lehesten in the Thuringian Forest may be mentioned.

When mica slate and gneiss are used as building stones, gneiss, or highly gneisose varieties of mica slate, should be selected for situations exposed to much wet, as the finer grained, or more slaty varieties, rapidly disintegrate; but where the building or any of its parts are likely to be exposed to much heat, as in the sides of chimneys and fire-places, the true mica schists, or the fine-grained varieties, are preferable. The city of Freiberg is built of gneiss, and its streets paved with the same material.

The most important of *the plutonic and volcanic rocks* are, granite, syenite, porphyry, greenstone, basalt. Many varieties of granite are excellent as building stones, though expensive in working to definite forms. Some of the most important public works of Great Britain and Ireland, France, and Russia (Petersburg), are of this material. In selecting granite, those varieties in which the constituent minerals are very small and the scales of mica superabundant should be avoided; and as a practical test it is wise to notice the country immediately around the quarry, as the sandy varieties rapidly disintegrate, and form accumulations of micaceous sand. The Hayter or Dartmoor granite, the Aberdeen granite, the Kingston (Dublin) granite, some beds of the Mourne or county of

Down granite, and the Guernsey or Channel Island granite, are well known for their excellence. In some of the quarries the bedding of the granite is more defined than in others; and wherever this is the case, or where marked cleavages or joints prevail, the working is much facilitated. Many old Egyptian works and statues were formed of granite, and it is still used for colossal works, as it takes a fine polish: for example, the great fountain shell or vase before the Museum at Berlin, and the pedestal of the statue of Peter the Great at St. Petersburg, are of Northern granite, being sculptured from erratic blocks. The splendid Scotch granite columns in the vestibule of the Fitzwilliam Museum at Cambridge are beautiful examples of a modern application of this rock to the arts. Millstones are occasionally manufactured of granite. As a road stone, those varieties which have at once a fine-grained and a close firm texture should be preferred, as the large crystals of coarser granite are liable to cleave into fragments. The specific gravity of this important stone varies from 2·5 to 2·6, which is very analogous to that of the metamorphic schists,—a circumstance which gives weight to Keilhau's opinion that in many cases it is a metamorphic and not an eruptive rock. Syenite is even a firmer stone than granite, and its specific gravity, which ranges from 2·5 so high as 3·0, approximates it to greenstone. Many beautiful varieties of this rock are found in Ireland. In Dresden, syenite is hewn into regular parellelopiped blocks for paving, a purpose for which its durability and firmness peculiarly fit it; and as a road stone generally it is excellent. Many ancient Eastern works were formed of it, and from its tenacity large objects have been fashioned out of single blocks.

Porphyry.—This term has an extensive application, as it may be used in reference to any rock in which isolated crystals, usually of felspar, are imbedded in a distinct paste. As a building stone, all those varieties having a soft argillaceous paste must be rejected; but there are many which afford good rough building stones, and also good road stones, easily

breaking into proper forms and sizes, binding well, keeping dry, and being tolerably free from dust,—a consideration too little attended to in the selection of road stones. From the beauty of its colours, some varieties of this rock have been largely used for columns, monuments, and vases. The red, brown, black, and green antique porphyries are well known to the student of ancient art. The red porphyry of the ancients is composed of a felspathic paste of a violet-red or wine-red colour having small crystals of black hornblende and grains of specular iron disseminated through the mass, and isolated crystals of a rose-red felspar. The paste contains 62 per cent. of silica, the isolated crystals 59. The crystals contain nearly 8 per cent. of soda and potash, of which only $\frac{1}{7}$ is potash; the paste 6 per cent., of which $\frac{1}{3}$ is potash. The paste is very rich in magnesia, the proportion being so high as 5 per cent.; in the crystals it is less than 2 per cent. This porphyry is distinguished from that of Elfdal by a lesser proportion of silica and a greater specific gravity, the quantities being thus: Red porphyry, silica 64; specific gravity 2·763: Elfdal porphyry, silica 78; specific gravity 2·623. It is to this excess of silica that the superior hardness of the Elfdal porphyry may be ascribed; and, as M. Delesse observes, the density of the porphyry may be considered an index of the quantity of its silica and consequently of its hardness. In modern times, the most remarkable porphyry works are at Elfdal, in Sweden, and Kolyvan, in Siberia. The Elfdal works have been established about sixty years; they are in the province of Dalarne, amidst wooded mountains, and in a wild country. The blocks are worked into form and polished by well-adjusted machinery; and most beautiful works of art as columns, vases, chimney ornaments, and tables, are produced, rivalling the rosso-antico, or ancient red porphyry. A magnificent vase of this porphyry, at the country palace of Johannsthal, is 10 feet high, and at its summit 16 feet in diameter: it rests on a base of granite. The principal dépôt of this manufacture is Stockholm. In the workshops of Kolyvan, in Siberia, equally beautiful speci-

mens of art are manufactured, and forwarded in large quantities to St. Petersburg. The blocks are sometimes of great size, 300 men being employed to draw a single block. Some of the porphyries of Hungary resemble the grey porphyry, the mordiglione of Roman artists. The specific gravity of porphyry varies from 2·4 to 2·8, and it may be observed that the beautiful polish it takes is a principal cause of its extreme durability; many works formed of it remaining uninjured for ages amongst the ruins surrounding them.

Greenstone.—The specific gravity of this rock ranges from 2·7 to 3·0, and though its extreme hardness, and the difficulty of cleaving it without splinters, render it less fitted for regular buildings, it may be used with advantage as a rough building stone, and for a road stone is excellent. The porfido verde-antico, or green porphyry of the ancients, noticed under porphyry, is a greenstone porphyry, the base being greenstone, with white and green isolated crystals of felspar. The Corsican globe rock is a compact greenstone with globular concretions.

Basalt.—This rock, so remarkable for the columnar structure so beautifully exhibited by many of its beds, as at Staffa and the Giant's Causeway (see also fig. 17), has a high specific gravity, varying from 2·8 to 3·1. In the more dense varieties its very great hardness makes it difficult of use for squared work; but for rough building, and especially for sea walls exposed to much wear, it is excellent. For paving stones it would also be admirable, were it not that the surface becomes polished and slippery; but as a road stone it cannot be excelled, making at once a firm, durable, and dry road. Though not common, some of the sphynxes and lions of the Egyptians were formed of basalt. Trachyte and the trachytic or felspathic lavas, and the various other products of ancient and modern volcanoes, naturally come into this section. In the county of Antrim largely, and in the county of Down in small quantity, trachytic porphyry has been found, assuming in Antrim a columnar structure. It appears also to be a product of the volcanic districts of New Zealand. It

forms a handsome and durable building stone. Of other lava products, such as tufa, the Romans used them extensively, as is observed in the ruins of Pompeii: when porous, they are very light, and may therefore be often applied with advantage where that quality, combined with strength, is of importance: their absorbent quality renders walls lined with them very dry.

Ophiolite or *Serpentine.*—The mineral 'serpentine,' by which name a massive and comparatively impure rock is also designated, is a bisilicate of magnesia, and has been well known from the earliest times. In all parts of the world, some of its varieties have been used in the formation of images for idol worship, and in the manufacture of vases, columns, pipes, &c. The rich green and bronze tints of its finer varieties, and the high polish of which they are susceptible, render it highly ornamental and valuable, and in Saxony it is still extensively worked. When veining carbonate of lime, it becomes the ophicalce of Brongniart, of which the green marble of Galway is an example; when porphyritic, it is his ophite.

Limestone.—It is associated with other metamorphic rocks in a manner which deserves especial attention. It is interstratified with mica schist, in layers varying in thickness from a mere film to beds several feet thick, and exhibiting the metamorphic change by a highly crystalline structure. When the crystals are not too large, it becomes a granular marble, and when veined, as in the county of Galway, with green serpentine, forms a verde-antico. Such marbles as these, including the finest statuary marble, which were formerly called primitive limestones, are of various ages; the marble here noticed, and that of Donegal, belonging to metamorphic rocks of a remote epoch, whereas that of Carrara is comparatively recent. In metamorphic districts, such as the mica schist country of Derry, Donegal, Scotland, &c., this limestone becomes a resource for lime, but it is impossible to notice its mode of distribution and the narrow scale of its development,

as compared with the mountain limestone of the carboniferous and the chalk of the cretaceous systems, without perceiving that argillaceous or muddy deposits there predominated.

Metallic Deposits.—In Europe the plutonic and metamorphic rocks are the great dépôts of metallic ores; and in South America, though gneiss is less productive and the ores continue into the overlying strata, it is highly probable that the latter have also been subject to metamorphic action, and that metallic veins have been connected in them, as in the crystalline schists, with electric phenomena.

Iron.—English iron is obtained from an ore not connected with metamorphic strata, which will be noticed in its proper place; but the celebrated Swedish iron is procured from magnetic iron ore connected with rocks of this class, and forming mountain masses in Taberg, in Smoland. This ore occurs in beds which sometimes alternate with the metamorphic strata at Dannemora, and various other places in Sweden, Norway, Russia, &c., and it has also been found associated with plutonic and volcanic rocks. The fer oligiste, specular or Elba iron ore, sometimes replaces mica in mica schist, and is associated with adularia at St. Gothard. The peroxide of iron forms veins and beds in these rocks, though it is also found, as well as the other ores of iron, in other deposits. *Manganese.*—Its peroxide has been found in metamorphic rocks, but it belongs more especially to sedimentary deposits.

Copper.—Copper pyrites, or bisulphuret of copper and iron, the most important of copper ores, occurs principally on the Continent in gneiss and mica schist; in Cornwall, and in the south of Ireland, in varieties of clay slate; in the Hartz in similar strata (or the old grauwacke); and in Tuscany at the junction of serpentine trapp (gabbro) with the tertiary strata. This mineral occurs also in the bituminous or copper schist (kupferschiefer), a portion of the zechstein, magnesian limestone, or Permian formation. In the Oural mountains, in Siberia, the double sulphuret of iron and copper is rare, and is replaced by the simple sulphuret of copper, the strata

being probably sedimentary: this ore occurs also in the porphyritic district of Tyrone. The other ores of copper do not here require a practical notice.

Lead.—Galena, or bisulphuret of lead, occurs in plutonic, metamorphic, and fossiliferous sedimentary deposits.

Silver.—Bisulphuret of silver, the most important of its ores, has been found in gneiss and mica schist and in their associated limestone, in greenstone slate, clay slate, syenite, and porphyritic greenstone. It extends up to the zechstein; but it should be here observed, that in some of these cases, as in Mexico and Peru, the veins run from the metamorphic to the ordinary sedimentary deposits, and have therefore been manifestly connected with the cause of metamorphic action.

Tin.—Binoxide (deutoxide) is the most important ore. In Cornwall, the great source of British tin and the most important one in the world, the ore occurs in granite, and also in killas, a partially metamorphic schist; and in other parts of the world, in granite, in metamorphic schists, or in porphyry, or porphyritic schists of the secondary class. Like gold, it is also worked as stream tin in sands proceeding from the disintegration of the tin-bearing rocks. *Zinc.*—Bisulphuret, usually associated with bisulphuret of lead. The carbonate belongs to various mineral deposits, extending even to the tertiary.

Mercury especially belongs to primary and secondary fossiliferous strata, though it is found occasionally in mica schist or crystalline metamorphic rocks, and in Haute-Vienne dispersed in globules in granite. The rich ore of mercury, cinnabar, of Almaden in Spain, is procured from grauwacke (primary) strata, and has been worked for ages.

Antimony.—Bisulphuret of antimony is rare, and found in veins traversing granite, gneiss, and mica schist. *Molybdena.*—The bisulphuret is found generally, in small masses, in granite and mica schist, and occasionally associated, though sparingly, with ores of tin, as in Cornwall, &c., and still more rarely with copper pyrites, as in Norway.

Gold has been found in Brazil disseminated in considerable

quantity in quartzose and chloritic rocks, which belong to the metamorphic system; and auriferous sands, which contain also platinum and diamonds, are the result of the decomposition of such rocks. Gold has in other places been found in veins traversing metamorphic rocks, from which the Wicklow gold sands have proceeded; and indeed the greater proportion of gold is obtained by washing from auriferous sands. Gold is very widely diffused in Nature, though usually in small quantities. In Russia the value of gold obtained from the Oural mountains amounts annually to about three millions sterling; but that procured from the New World exceeds greatly even this large return. Independently of the old mines of South America and those of the southern portion of the United States, California furnished to the Philadelphia Mint in 1850 six and a half millions sterling of gold,—a quantity which probably exceeds that furnished by the rest of the world. An announcement has also been made in the public journals of the recent discovery of valuable gold mines in Australia. *Platinum* is associated with gold in the auriferous sands of Brazil, of Russia, and of Wicklow in Ireland; it has also been discovered in France.

This general occurrence of metallic ores in rocks which have undergone a metamorphic change, though at very various epochs, their occurrence in veins, and the facts observed by Mr. Fox of the conduction of electricity by mineral veins, and the development of metals and minerals near the contact of highly metamorphic strata, stated by Keilhau, are strong reasons for ascribing their presence under such circumstances to an electric cause.

Veins.—As the term vein occurs frequently in this section, it is desirable to explain it. The idea which the word conveys is distinguished from that of dykes, as it implies a waving rather than a rectilineal course; but this distinction is not always preserved, as many veins, and particularly metallic lodes, are rectilinear. Veins may, however, be placed in two sections; namely, those which, unconnected with any great

extraneous mass of matter, originate in and are confined to the rock in which they occur, and those which spring from and are connected with some great extraneous mass. The first may be found in all rocks, are often so fine as to be quite capillary, and frequently intersect each other, forming a complete net-work: they are considered veins of segregation, having been probably cracks into which the crystalline matter now filling them has been gradually removed from the surrounding mass. They consist sometimes of quartz, and sometimes of carbonate of lime. The others are often connected with large masses of external rock, the matter of which is identical with that of the veins; and it has therefore been very generally assumed that such veins are veins of intrusion, though by Keilhau they are considered an advanced product of metamorphic action. Where metallic veins pass through various strata, the sedimentary included, they have most probably originated in cracks consequent on disturbing movements from below, and have been filled partly by segregation, modified as to its results by electric currents, partly by sublimation, partly by the decomposition of volatile perchlorides, fluorides, and borides which have permeated the earth's crust through such channels, and partly by infiltration. Some of these veins are of great magnitude, an example of which may be cited in the great ironstone vein of the red mountain near Schwarzenberg, which is between 40 and 50 feet thick, and stretching along the boundary between the granite and gneiss (partly in the gneiss itself) has been traced for about four miles.

CHAPTER V.

Fossils — Petrifactions — Conditions of Petrified Bodies, and Modes of Petrifaction—Petrifying Substances—Distribution of Fossils.

The term fossil, in its original and natural sense, might be applied, as it formerly was, to any body dug out of the earth,

and would then comprise minerals, metals, and all other substances thus obtained. Amongst such fossils there were occasionally found mineral bodies which exhibited so strong a resemblance in their external forms to known organic structures, that it was impossible not to ask—are these bodies merely the production of some fanciful operation of Nature's powers, or are they really relics of organized beings? The progress of discovery soon led to the rejection of the first of these theories, and for a time geologists, deceived by a general resemblance and overlooking the specific distinction between fossil and existing organisms, explained the occurrence of organic fossils within the solid matter of the earth by the operation of the great Deluge, which they supposed to have torn up the crust of the earth and spread its comminuted fragments over the surface mixed up with shells and other organic bodies which were living at the time of the great catastrophe. The labours of modern philosophers have dispelled this second error, and established a new science, Palæontology (doctrine of ancient or extinct animals), by discovering that fossil organic bodies are specifically and often generically distinct from any now living, and are therefore, as relics of extinct animals, the records of successive phenomena which involve the appearance and disappearance of organic bodies, under forms and combinations suited to the varying conditions of the earth's surface.

The weight of this evidence in favour of the existence of assemblages of animals and plants, which at successive epochs of the earth's history have been swept away, may be estimated from the fact that probably nearly 30,000 species of fossil animals and plants have been discovered and described; a number which is very great, for though more than 170,000 existing animals and plants are known to Naturalists, it must be remembered that very many of them belong to classes representatives of which, either from the nature of their habitation or from the soft and perishable character of their bodies, cannot be expected to be found

in a fossil state. Of the number of plants which have thus lived at ancient epochs and passed away, some idea may be formed from the rich collection of Goëppert, author of 'Les Genres des Plantes Fossiles,' &c., which contains more than 3000 specimens of vegetable petrifactions; namely, 236 from Cambrian and Silurian strata, 1548 from the carboniferous, 95 from the trias or new red sandstone, 61 from the lias and oolite, 242 from the green-sand, chalk, and gypsum, 742 from lignites, 259 of unknown localities, and 50 of recent forms, which occur in three conditions.

1. Stems, leaves, flowers, fruits, interposed between layers of stony or earthy matter, and either slightly browned, or in various states (up to the most perfect) of carbonization.

2. Impressions of the bark of plants, the interior of which is either empty or filled with stony matter.

3. Complete petrifactions, in which the whole of the interior mass, as the several organs, cells, and vessels of the plant, are *filled* with stony matter, and not, as is commonly said, *changed* into stone.

M. Goëppert illustrates the first by experimental imitations of the distribution of fossil plants in shales and grits. Living plants, particularly ferns, were placed between layers of soft clay, which were then dried in the shade, and afterwards exposed to heat varying in intensity up to a red heat. According to the degree of heat, the plants were found either slightly browned or perfectly carbonized; and when either powdered coal or asphalte had been mixed with the clay, they exhibited a shining black tint, and adhered to the layer of clay. When the heat had been pushed to redness, and the plants were entirely consumed, impressions of both faces were found, just as in the grits of Silesia. In the second experiment, the plants were placed between layers of clay, and were left immersed six feet deep in a ditch for a whole year, when they were more or less browned (as plants are when naturally immersed in the mire at the bottom of ponds), and might have been mistaken for the impressions of fossil plants.

In the second condition, which has not been fully illustrated by experiment, the bark of the plants sometimes remains and resembles coal, whilst all its external peculiarities are impressed on the surrounding matrix, and the markings of the internal surface are exhibited on the stony cast formed within it; so that in such cases the cast and the mould have frequently been taken for different bodies. Sometimes the bark is reduced to a film of coaly powder between the impression of the mould and the cast; and as the decomposition of the thin bark of such plants preceded the formation of the cast, the impression of the mould corresponds at once to the original external surface of the plant, and to that of the cast. When decomposition and petrifaction have taken place under pressure, the stems are more or less flattened; and in some calamites the opposite surfaces have been pressed close together, the whole internal substance having been removed before the consolidation of the surrounding mass had secured it from the effect of pressure.

In the third condition, mineral matter has been infiltrated into and has solidified within the interstices of the cells and vessels, the walls of which have been more or less preserved. In vegetable fossils the ordinary petrifying substances are silica, carbonate and sulphate of lime which are soluble in water, peroxide of iron, smooth clay, or a mixture of several of these ingredients; and M. Goëppert proves that the process is still going forward, by specimens of oak received from M. Cotta and from M. Laspe, which were taken from a brook, and having been fossilized by carbonate of lime are hard enough to take a fine polish, the vessels and cells, excepting some of the medullary rays, being entirely filled with carbonate of lime. In a specimen of wood from a Roman aqueduct, petrifaction is confined to cylindrical spaces traversing the ligneous structure longitudinally, which were probably vacant spaces produced by decomposition and filled up by stony matter. The wood surrounding the petrified portions is perfectly sound; and under the

microscope the exact identity of structure of the woody and stony portions can be clearly traced. On applying an acid the earthy matter is removed, and as the ligneous portion still contains tannin, perfect decomposition had not preceded petrifaction. The stave of a cask which had probably been immersed in the well of the castle of Gotha for one hundred and fifty years, was in part, especially at the junction of the hoops, petrified by peroxide of iron, and was so hard as to take a polish by friction. Where the iron has been removed by muriatic acid, the wood continues in a solid and coherent state. In calcified specimens of the fossil woods of the ancient world, from various localities and of different ages, including that from Craigleith, in Scotland, the same results are observable, the woody fibre remaining after the removal of the earthy matter by very dilute hydrochloric acid; and from some specimens, a bituminous oil, emitting a mixed odour of creosote and petroleum, may be obtained, which is an additional proof of the formation of bitumen under aqueous pressure. M. Goëppert has not discovered any recent silicious petrifaction.

Though wood fossilized by gypsum is very rare, there is a specimen from Silesia, weighing 4 quintals, in the museum of the University of Breslau, of which the ligneous fibre is only in part fossilized, the rest being flexible. In many silicious vegetable fossils, M. Goëppert, after removing the silica by hydrofluoric acid, found the woody fibre so well preserved that it might be used in determining the genus of the plant. When in fossil woods treated with hydrofluoric acid no organic matter can be discovered, it has been doubtless removed after fossilization, either by long aqueous action, or by heat. When slices of the petrified coniferæ of Silesia which still retain a portion of ligneous fibre are exposed to the action of a furnace, the fibre is destroyed, and the specimens, before variously coloured, become uniformly white and opaque, the characteristic structure of the coniferæ being very distinct. It is, however, remarkable that the ligneous fibre has been

preserved in some fossil woods found in ligneous rocks, as porphyry, basaltic tufa, and even basalt, which must have been subjected to heat, and it appears therefore certain that water is a principal agent in the removal of organic matter, as M. Goëppert has proved by specimens of fossil wood from Glatz, which had been rolled about in a brook running from the mountain and contained less organic matter in proportion as they were more rounded, or had been more subjected to the action of air and water, the diminution taking place from the centre outwards. As in this instance the disorganization was effected in a very short time, is it not surprising that any traces of organic matter should be found in specimens which have been exposed to the air for more than 1000 years? The agatized woods of Hungary, which occur in the horizontal beds of a conglomerate of pumice which forms the basis of a trachytic group, are externally beautifully transparent, from the absence of organic matter, and from the presence of water in the outer portion. Exposed to the flame of the blow-pipe, they lose their transparency, become white and opaque, and, from the dilatation of the water, split along the direction of the ligneous fibre, so that it is possible to separate the ligneous cells from each other. In the Tokay fossil wood, the colour, as well as the organic matter, is still preserved; and in the Antigua agatized palms, the delicate spiral vessels can still be recognized. In general, when much organic matter is left, the specimen is more highly coloured; but at times the tint is derived from the mineral matter. The organic fibre of fossil plants which remains upon the removal of the stony matter by an acid when subjected to great heat, is burnt away, and leaves, as in recent plants, a silicious skeleton; and when we reflect on all these curious facts, we learn with admiration that not merely the forms of bodies, but the organic matter itself of ancient creations has been preserved for our contemplation and study.

The various circumstances and conditions of fossil vegetables at all epochs have led M. Goëppert to conclude that the forces

which are now in action were sufficient to produce the effects observed, and that the water of the ancient world *did not* possess a higher solvent power than that of the present. Water dissolves about $\frac{1}{1000}$th part of silica, and the ease with which it entered, as a fossilizing agent, into the vegetable structure is proved by the concretions on the bamboo, called tabasheer, and the large quantity of silica deposited in the tissues of some other living vegetables.

Coal and lignite are vegetable fossils, and M. Wiegmann has made experiments in the moist way to illustrate the formation both of turf and of lignite; and examples might be cited of corresponding changes taking place in a natural way, as in fragments of ancient carpentry changed into lignite from the mines of Charlottenbrunn, and in specimens of wood-work sent to M. Goëppert from the iron mines of Zurrach in Stiria, which, in the space of less than sixty years, had been changed into resinous lignite; and in others from the sepulchres of the aborigines of Bohemia. According to M. Liebig, hydrogen escapes in disintegration; whilst in putrefaction, oxygen is disengaged: when, therefore, the latter change takes place under a high pressure, and at an elevated temperature, considerable quantities of carbonic acid will be disengaged, and at the same time much carbon be deposited in combination with a part of the hydrogen of the organic substance, and it is probable that coal and some lignites have been the result of such operations. M. Link has endeavoured to show, by comparative microscopic observations, that turf and coal are analogous in structure, and may have been produced the one from the other; and stems of trees which occur in coal are very analogous to those which are frequently found in successive layers in the deep turf of Ireland. The formation of coal by immersion in water, under pressure, was suggested long since by Dr. McCulloch. Messrs. Mareel de Serres and L. Figuier have illustrated the general principles of petrifaction, by the petrifaction of shells in the Mediterranean. They suppose, however, that the waters of the ancient ocean did possess a higher solvent power than they do at present;

but in reality this difference is apparent rather than real, as the presence of so much alkaline matter since deposited in combination with silicic and other acids must have rendered the water a more powerful solvent than it now is. The action of every natural force tends to a resulting equilibrium, and *if* that has *now been attained*, the same processes will continue without producing any difference in the great aggregate of the animal, vegetable, and mineral kingdoms; but if not, such a difference must, however gradually, be produced. The long existence of the present assemblage of created beings, and the effective condition of the atmosphere, which remains unaltered by vital agencies, are strong reasons for believing that an equilibrium has been attained; and as a further proof, it should be stated that the world has only lost, during 6000 years, about twelve vertebrate animals, and that principally from the action of man, although the distribution of animals has been materially modified by the local extinction of some, and the lateral extension of other species.

Fossils and Petrifactions.—From the preceding pages the student must have already learnt that the terms 'Fossil' and 'Petrifaction' cannot be used indiscriminately or considered synonymous. The word fossil, as understood by Geologists, means indeed the remains of some organic body found in a position and under circumstances which prove that it never could have been a member of the existing system of living organisms; but it is not necessary that every fossil should have become a petrifaction—that is to say, have been changed into stone—as is proved by the condition of coal, and still more by that of lignite, which retains, though manifestly an organic fossil, the ligneous structure and fibre. Coal has indeed undergone a chemical change by the partial re-adjustment of its elementary constituents, and the consequent development within its substance of bitumen, but it has made no approach to the state of petrifaction. In like manner, the examples cited have shown that many organic bodies, in all respects identical with those now living, may have become petrified

during the course of the still passing system of creation, and have therefore no claim to be called fossil. In either case the mere condition of the body is not sufficient to determine whether it is or is not a fossil; and much caution, therefore, is required in using these terms. The passage of an organic body from the ordinary to a petrified state, which is often improperly called fossilization, is influenced by many circumstances, of which the chemical constitution is one and will be first noted,—though it is necessary to premise with Messrs. Serres and Figuier, that in order to induce the petrifaction of organic bodies, in which process the animal matter is replaced by mineral substances, they must be plunged either in a considerable quantity of water which contains in solution a sufficient proportion of silicious, calcareous, or other salts, or in semi-liquid muds or other deposits which permit a free access of such saline solutions: a condition which was fulfilled in the ancient world when the waters spread over large spaces now occupied by land which, both from its mineral and organic characteristics, must have been deposited under water, and when they were rich in dissolved salts, as is manifest from the extensive deposits of carbonate of lime, of gypsum, and of rock salt.

The *bones* and *teeth* of *Mammals* are closely connected with the mineral kingdom in their natural condition;—bones containing $55\frac{1}{4}$ parts in a hundred of phosphate of lime with a little phosphate of magnesia and fluoride of calcium, $12\frac{1}{2}$ parts of carbonate of lime with a small quantity of soda and chloride of sodium, or nearly 68 parts of mineral matter combined with about 32 parts of organic matter; and teeth containing sometimes from 64 to 66 per cent. of phosphate of lime. In *cartilages* the gelatine increases to so large a proportion that there are only 1 or 2 per cent. of mineral matter, and it will, therefore, be easily understood how rapidly they must decay and pass away, and how little they could be expected to retain their form and admit of a petrifying change. The *tusks* of animals and the *horns* of deer are very analogous to teeth and

bones. The composition of birds' bones is nearly the same as that of quadrupeds, but as they are porous, their density is much less, and the quantity of earthy matter is therefore less for the same *bulk*. The *bones* of *fishes* contain much less earthy matter, and on that account are rarely found in a fossil state. The horns of ruminants, as oxen, sheep, &c., the scales of reptiles, and tortoise-shell, are very analogous, being modifications of the skin, and are poor in mineral matter. Scales of fishes, on the contrary, contain from 42 to 46 per cent. of phosphate of lime, and hence are frequently found fossil, whilst those of reptiles are comparatively rare. M. D'Orbigny observes, that whilst the fossil scales of reptiles are either petrified by silica or carbonate of lime, those of fishes retain a considerable quantity of phosphate of lime, as proved by the analyses of M. Huyard; and hence suggests chemical examination as a test when there remains a doubt to which class the scales should be referred. Claws, spines, bristles, hairs, and feathers, are merely appendages to the skin, and, containing very little mineral matter, putrefy and decompose so easily as rarely, if ever, to be found fossil. The shells or crusts of that portion of the Annelides called Crustacea, of which lobsters and crabs are familiar types, contain from 50 to more than 60 per cent. of mineral salts united with various organic substances, and were, therefore, sufficiently stable to be preserved in a fossil state.

But, without dwelling on other organic bodies which have been rarely, and then from accidental circumstances only, discovered in a fossil state, let us pass to those which, from their composition alone, might be classed with minerals,—namely, the shells of *Mollusca*. Of all animals, they have left the greatest variety and number of fossil relics,—a fact which their chemical composition would of itself explain, even were it not in part a result of the peculiar conditions and circumstances under which they lived. The shells of Mollusca consist of about 96 per cent. of carbonate of lime, 1½ of phosphate of lime, 1½ of water, and of animal matter only 1 per cent.; or

in some shells, such as those of oysters, scarcely an appreciable quantity, which accounts for the great masses of oyster-shells (including the allied genera exogyra and gryphæa) which are found in so many formations. The stony cases of *Polyps*, or *corals*, are in like manner mineral bodies, as they contain from 97 to 98 per cent. of carbonate of lime, besides small quantities of magnesia, alumina, iron, and silica, combined with phosphoric and fluoric acids; and such a composition explains the formation of those extensive beds at many geological epochs which are almost entirely made up of corals, and are so analogous to the coral reefs and islands of our present tropical seas.

Fossil shells, like fossil plants, occur under various forms: in some the interior has been filled, after the death and decay of the animals which inhabited them, with foreign mineral matter either analogous to that of the shells or at times not so, aud a cast has been thus formed in which may be frequently observed in relief the muscular impressions which the animal had made on the internal surface of its shell: in others, a mould has been formed round the shell, and in this manner the peculiar markings, as ribs, furrows, &c. of the external surface were preserved, even though the shell itself had been removed; and a cast being subsequently formed by the infiltration of sedimentary or dissolved matter into the hollow space, the external form of the shell was reproduced, though frequently in a substance totally different from the original carbonate of lime; and again it often happens, that though the shell appears the same in form and substance as it originally was, the structure is physically quite different; and this leads us briefly to notice the processes of petrifaction, or those processes by which an organic body loses more or less of its primitive nature, and is converted into a new substance, though still preserving the organic form.

Petrifaction by abstraction of matter.—This is the case with most comparatively recent fossils, as the bones of caverns, &c., in which the change is almost limited to the removal of organic matter. It might be supposed that this limit would

be always observed in fossils of contemporaneous origin with the shells and other organic bodies still existing, but in the Mediterranean examples have been discovered of much higher changes, whilst it has been ascertained that the change is not perfect even in many older fossils. Thus Messrs. Serres and Figuier observe,—1stly, that shells are found in the Mediterranean in all stages of the petrifying process, from simple discoloration to the complete transformation into crystalline carbonate of lime; 2ndly, that the molecular structure of recently petrified shells is very often different from that of ancient fossil shells, the first being usually crystalline, the others usually compact; though in many ancient fossil shells a crystalline structure is very perceptible, distinguishing them at a glance from the surrounding compact limestone; and thus affording another confirmatory argument in favour of the identity of the process at all ages of the world. By a comparative analysis of the substance of living, of recently petrified, and of fossil shells, genera common to the three epochs of comparison being selected, the effects of petrifaction were tested; and it was ascertained that a portion of animal matter was still existing in shells of the pliocene formation.

The officers of the French Engineers submitted to Messrs. Serres and Figuier specimens from the neighbourhood of Algiers, of masses of shells transformed into a crystalline white limestone of a peculiar lustre, like that of alabaster. In these shelly masses, small rolled pebbles are observed incrusted by a stalagmitic glaze, which appears to be similar to the cementing substance which binds the pebbles together. The shells are all of recent species of the genera pectunculus and cardium, with a few univalves, and the rock itself is considered by the officers of Engineers to be decidedly of recent origin; and another interesting fact may be cited in the remarkable conglomerate now forming on the shore of Santa Maura, and at other localities, and which in its cohesion is fully equal to many ancient rocks of the same description; there being a continued tendency to such aggregations, even

from other than calcareous agencies, as is seen in an interesting specimen, also from Santa Maura, presented to the author of this volume by Mr. Cottam, in which several pebbles have been agglutinated firmly together by the decomposition of a nail, to which they still strongly adhere; and in a similar instance at one of the batteries of Portsmouth, where a conglomerate has been formed round the iron shoes of the piles. Messrs. Serres and Figuier state also, on the authority of others, that the cardium edule, in a petrified state, forms considerable beds at the mouth of the Somme, and that at Caneale the shells of oysters have been petrified in the same manner as in the Mediterranean.

Petrifaction by incrustation is a combined mechanical and chemical process, in which a body becomes enveloped and partially penetrated by mineral matter which is deposited upon it, just as crystals of alum or of sugar are formed round a thread or stick when plunged into a saturated solution. The substances usually concerned in this operation are carbonate of lime and silica, more particularly the former, which is soluble in water containing carbonic acid, as all spring water does. The manner in which such incrustation is effected may be readily observed in fountains and springs which are highly charged with carbonic acid, as the excess of acid escapes on coming into contact with the air, and the calcareous matter incrusts the moss, leaves, or other bodies exposed to its action. When this is long continued, a mass of calcareous tufa is formed; and in a similar manner, in fossils, a crust might have been formed sufficiently thick to retain the form of the body after its substance had been removed by decomposition. As the deposition of matter proceeds, it will fill up the cavity, and thus become a cast of the organic body: here, therefore, similar results may be obtained as in the preceding cases. Sulphuret of iron and of copper, peroxide of iron, and some other substances, occasionally occur as incrusting bodies; and in the tertiary clays concretionary incrustations are frequently found enveloping organic bodies, which, though altered, have not been entirely replaced by mineral matter.

Petrifaction by the mechanical introduction of sedimentary matter.—Where the organic body presents a large and easily accessible cavity, mineral matter gradually fills it up. This matter is sometimes very coarse, and it is in this manner that petrifactions in sandstones have been principally formed. Enveloped in and filled with sand which has become cemented perhaps by matter proceeding from part of its own substance, the organic body, whether a bone or a shell, may be entirely destroyed, and thus at once leave a mould of its exterior and a cast of its interior, or it may be only modified by changes which will be now described.

Petrifaction by molecular penetration and by substitution.—When an organic body has been partly disorganized, it may become so porous as to allow even fine matter held in suspension, and still more so matter in solution, to penetrate through its tissues, or, in other words, solid matter may be thus filtrated through the organic body. In this manner a body may be permeated by mineral matter long before the total removal of its organic constituents, and whilst the more accessible cavities have been filled by coarse materials introduced through distinct openings, the internal cavities may be also either filled with very fine matter which has passed through their coatings or walls, or lined with crystals separated from matter in solution. This change is sometimes so complete that it *amounts* to a substitution of one form of matter for another, and the result, therefore, represents in every minute particular the original body, though in a totally different substance. Vegetable fossils afford many examples of this substitution of mineral for organic matter, and it is often possible to detect in the petrifaction the most delicate vessels of the organic body, and thus to determine with the greatest precision the genera of plants. In plants this substitution is principally effected by the introduction of silica, and in like manner the animal or more purely organic portion of other bodies are also petrified by silicious matter; the ligaments, for example, of gryphites becoming silicious whilst the shells are calcareous, and the

interior of many echinidæ, or sea-urchins, being filled with silex whilst the thin crust or shell remains calcareous, there being apparently an elective affinity between organic matter and silex.

Petrifaction by chemical change and by transformation.—In these cases there is no mechanical introduction of mineral matter into an organic body, but a chemical action by which either the original component parts of the body are brought into new combinations, as in the change of organic structures into bitumen, or the elements of the body are made to combine with external substances, and thus to procure a metamorphosis of the fossil, as regards its composition. In the case of ***transformation***, there is actually no change in the substance, but merely an alteration in the molecular arrangement of its particles. This change of ***physical*** condition might be illustrated by reference to the changes which are effected in sulphur and phosphorus by heat, and it is abundantly exhibited in fossil shells, which, though when recent they are compact, or rarely fibrous, become in the fossil state lamellar, crystalline, and finely fibrous, or undergo other physical changes, such as that from opacity to translucence, &c. In ancient petrifaction, carbonate of lime was the principal agent, and the fossilization was complete in proportion to the abundance of that salt present. In gypseous, argillaceous, and even sandy deposits, petrifaction is imperfect and the shells of mollusca are only in part preserved.

Water dissolves carbonate of lime when an excess of carbonic acid is present, as is always the case in nature; and in consequence, an appreciable quantity of ***bicarbonate*** of lime exists in sea water, and is one of the many examples of a balance between the formative and destroying causes constantly in action. Innumerable springs charged with carbonic acid dissolve the carbonate of lime of ancient formations, and carry it to the ocean, whilst the mollusca, &c. again withdraw it, and liberate the carbonic acid to return to the atmosphere. The shells of the mollusca again pass into new mineral deposits, either whole

or triturated into powder; and the same may be said of the corals and other zoophytes. In regard to silica, which is the next most important petrifying substance, and even exceeds carbonate of lime in the extreme delicacy and fidelity of the restoration it produces, it has already been stated that the water of almost all mineral and thermal springs contains a portion of it, that it occurs in most rivers or streams, and that it abounds in the stems and membranes of many vegetables. Combined heat and pressure favour its solution,—as is shown by the great quantity deposited at the foot of the boiling Geysers of Iceland,—and it is greatly promoted by the presence of an alkali which is usually afforded by the decomposition of rocks; and further, in the gelatinous or nascent state, in which it always occurs on the decomposition of a mineral, it is readily soluble. Silica, therefore, must have been in solution prior to the formation of rock crystal, and, probably, in a gelatinous state when forming chalcedony, opals, and some of the flints and cherts of various geological formations. Oxide of iron, anhydrous or hydrated, and bisulphuret of iron, have also entered into the formation of fossils: in respect to the latter, the change, as in silica, is principally produced on the animal substance; for example, the ammonites in shale exhibit a mere film of shining iron pyrites, which has replaced the animal membrane.

From the processes of petrifaction, it is necessary to turn to the consideration of the mineral beds in which petrifaction occurs, and to determine the exact relations of the beds to the fossils they contain. On studying the still passing operations of Nature, it becomes evident that many forms of mineral deposit are in course of production, such as the sand dune or hill, which though removed from the action of the sea is still shifted and modified by the action of winds, and in which land and marine shells and fragments of bones are enveloped by the drifting sand, and the various deposits of mud, sand, gravel, or shingle, forming in the bays and estuaries, or on the coast of the ocean, in all of which relics of organic bodies may have

been entombed, as the same force which operated in moving the mud or gravel was equally efficient for transporting the organic bodies. But in these cases there may not have been an original connection between the fossils and the mineral beds in which they are found, the inhabitant of a sandy sea bottom being hurried, when no longer possessed of a vital force of resistance, by the currents and deposited amongst the muddy sediment of an estuary. Many such confused assemblages must doubtless have been formed, but the correct observations of modern Zoologists afford a clue to the discovery of the real inhabitants of the several deposits, and to the separation from them of extraneous bodies; for example, it has been determined by Professor Edward Forbes that the vertical range of marine mollusca is restricted to definite limits, so that some are specially littoral or shore inhabitants, and found on the rocks or on the gravel or sand which is washed and left dry alternately by the tidal wave, whilst others live at successive and increasing depths below the surface of the ocean. And further, it is known that some mollusca or shell-fish live buried in the sand or mud, whilst others rest on the bottom, either adhering to stones or rocks, or kept in their place by their weight alone; so that a careful comparison of a cluster of such fossils will greatly assist the skilful Geologist in determining which should be assigned to the particular bed as its natural inhabitants, and which should be considered extraneous bodies derived from drift, and thus to recognize the influence exercised by the petrographic constitution of the bed itself on its fossils. Organic beings are, indeed, not only restrained to a particular medium in which they can alone live, but require also a peculiar collocation of circumstances suited to their individual existence: thus one fish may be marine, another fresh-water,—one may live in open and deep seas, another frequent rocky coasts and clear water, a third delight in the muddy shallows of estuaries; and in a similar manner mollusca are regulated in their habitats by the necessary requirements of their organization;—a limpit

being attached to a rock, and able to sustain the beating action of the wave,—the cockle inhabiting the gently-sloping sandy shore in shallow bays,—the myacea burying themselves in similar strands,—the pinnæ frequenting the muddy bottoms of deeper waters,—whilst many genera with strong shells can bear the force of currents, and rest uninjured on shingle banks or rocky bottoms. As the Naturalist, therefore, does not look for the animal suited to a muddy bottom on a shingle bank, or for the thin-shelled spatangus at the bottom of a rocky cliff exposed to the violent action of the tidal current, so the Geologist must exercise a like caution in his research, and remember that—1st, A peculiar petrographic constitution in a stratum will be accompanied by a peculiar palæontological assemblage of fossils; and 2ndly, That such a palæontological assemblage does not naturally include genera and species suited to strata of a different petrographic constitution: and therefore, when genera or species peculiar to one form of mineral stratum be found in another, they may be expected to be rare, much less developed, and less distinctly characterized than in the stratum to which they properly belong.

Combining the actual mineral structure of the stratum, which is a result of certain necessary conditions, with the modifying circumstances of position, deposits may be considered as shore or littoral deposits, shallow-sea deposits, deep-sea deposits, coral-bank deposits, &c.; and the probable occurrence of organic bodies must depend on their adaptation to those circumstances, so that it may be assumed, as a very important character, that in organisms of the coralline type of deposit, the shell or crust is massive, and marked by ribs, striæ, spines, knobs, and other peculiarities, which, whilst they doubtless added to their fitness for opposing the contingencies of their peculiar location, now afford so many valuable characters for studying them as inhabitants of an ocean long since passed away. Shingle deposits produced by the more active wear of the waves, though often intimately connected with coral banks, accompany and link together all the petro-

graphic forms of deposit. They possess few zoological peculiarities, borrowing, as it were, the characters of the several deposits with which they are connected, by receiving from them the fragments of their various organisms, which are gradually, as they are carried along, worn down, passing through an oolitic state into an impalpable paste. Muddy deposits, such as marls, compact and sub-compact limestones, together with sands and sandstones, constitute another important class, and exhibit a totally different zoological assemblage: the corals are of spongy and incrusting genera, and generally without apparent base; crinoids are rare, scattered about, and generally of unattached genera; the echinida are less rare, particularly the true echini and their congeners, and the spatangi abound in muddy and sub-sandy deposits. Of the asterida, the genera asterias and ophiocoma are characteristic of muddy deposits, and of fine sands and gravel. Of the acephalous mollusca, the genera which abound are, solen, pholadomya, myopsis, pinna, tellina, mytilus, modiolus, corbula, isocardium, cucullea, and amongst the ostracea, gryphæa and exogyra. In the gasteropoda may be noted, rostellaria, pterocera, natica, turritella, fasciolaria; and amongst the cephalopoda, the genera nautilus, ammonites, belemnites, being either rare or abundant, according to the variations in the form of the deposit. Fish with pavement-like teeth are very characteristic of these mud deposits; and reptiles are especially abundant in the Jurasic beds, though they are locally rather than generally distributed, occurring in what may be deemed muddy shore deposits. A general and constant character of all zoological assemblages in muddy deposits, is that the prevailing genera and species are provided with shells or coverings not fitted to withstand the wear of transport, being smooth and thin; and in those genera which possess a thick shell, the tissue is nearly non-elastic and easily disintegrates. It may be also stated, as distinctive of muddy bottoms, that the genera are more frequently free than attached, even the stems of pentacrini not exhibit-

ing strong roots, having been probably fixed by fibrillæ or simply immersed at their base in the mud.

The sub-pelagic and pelagic forms of muddy deposits, though corresponding to the littoral form in their petrographic conditions, are distinguished from it by zoological peculiarities.

The deep-sea or pelagic deposits are very uniformly constituted, homogeneous, regularly stratified in continuous and often massive beds, except where modified or disturbed by the action either of currents or of elevating forces. In these deposits, large spaces are often deficient in organic bodies, or contain only their débris, together with those spongy and fibrous corals which are supposed to inhabit the waters of great depths; and where cephalopoda abound, the species differ from those which inhabit muddy shore deposits. M. Gressly arrived at these important deductions from the preceding facts, having thus as it were adopted views very similar to those which have been so ably set forth by Professor Forbes

1. Each class or form of deposit presents characters, petrographic, geognostic, and zoological, peculiar to itself, and distinct from those of any other class or form of deposit, although of the same geological epoch.

2. That the same class or form of deposit, as regards its petrographic and geognostic condition, exhibits very analogous zoological characters in each successive geological formation in which it occurs. These two laws are of great interest, and highly important in the application of zoological characters to the determining of geological formations; though it is necessary to take into account, as already pointed out, every disturbing or modifying influence, in order to separate, in any stratum, those organisms which are peculiar to and must have found a fitting habitus in it, from those which have only been brought into it from other situations by currents, storms, &c. In the muddy sub-pelagic bottom of the channel of Corfu, in the Ionian Islands, many of the thin-crusted and silky-spined

spatangidæ are found, together with nuculæ, tellinæ, corbulæ, and other organisms fitted for such a habitus; but these are combined with abundant exuviæ of other organisms foreign to such a habitus,—as the valves of strongly-ribbed cardia, pectens, &c. In the one case, the shells, &c. are generally perfect or alive; in the other, more frequently separated and injured; and in bivalves though still connected, they are often found open and the valves twisted round; and the Geologist will find many similar cases in the deposits of ancient worlds.

3. In every petrographic class of deposits, two sets of organisms may be expected to occur: the one suited to the habitus afforded by its geognostic position, and therefore the truly characteristic organisms of that class of deposit, or those which should be used in any comparisons between distant deposits of the same or of any other formation; the other, extraneous organisms, the absence of which at some other locality would not be evidence of a geological difference, but simply of freedom from the modifying influences which had affected the first locality. There are many other geological facts on which much light is thrown, if they are not fully explained, by the method of comparing the conditions of zoological existence at ancient epochs with those of the present, such as the abrupt terminations of peculiar petrographic deposits, the local distribution of fossils, &c., cases which can be observed wherever a mud or other bank is cut off by a current, or where a local deposit is formed under the lea of projecting rocks, or the shelter of a coral reef; but it would be vain to attempt to note them all, and enough has been said to guide the observer to a right mode of geological inquiry in tracing out the lateral extension of any particular formation. When the inquiry is made in a vertical direction, or by the aid of natural and artificial sections, the observer will find the same classes of deposit recurring at different intervals, and will discover a similar analogy in the assemblage of organisms connected with them; an analogy, such as similar conditions of existence must produce,—not an identity, which could

alone spring from identity in the organisms of the two periods. He is thus led to another geological rule or principle.

4. Similar variations in the conditions of organic existence must produce similar modifications in the assemblage of organic beings which exist in various places at the same epoch. Want of identity, therefore, in the organisms of the same petrographic class of deposit in successive portions of a section of any part of the earth's crust, cannot be explained by a variation of the conditions of existence; the petrographic and geognistic *identity* combine with the zoological *analogy* to show that the conditions were really the same, and the change must be ascribed to a difference in the aggregate fauna and flora of the epoch: or, in other words, it proves that the organisms of successive strata were connected with distinct acts of creation, or formed parts of distinct organic systems or worlds.

As a relation exists between the shell or covering of the animal and the petrographic condition of the deposit in which it is found, it must be assumed that the animal itself was formed to exist under the physical forces which gave rise to that deposit, and that its general organization was suited to all the circumstances of its destined habitat. Temperature and pressure are the two forces which most materially affect marine organic existence, and restrain or promote the distribution of marine organic bodies; but it may be asked in what manner the stream of organic life commenced? The earliest historical record of the human race describes a local creation; and though the learned dispute as to the precise time involved in the events noted, the Mosaic account is in favour of the theory of a centre of creation: and if the past worlds of former geological epochs be also taken into consideration, the more general principle of centres of creation may be safely adopted as more conformable to the simplicity of nature, than a contemporaneous or even a successive creation of the same species at various and distant localities.

A group of animals being created with organizations suited to certain conditions, such as the breathing of air or water, and

the capability of supporting a certain degree of heat or amount of pressure, when the mandate was pronounced that they should multiply, their lateral progression on the earth would be controlled by the laws implied by those conditions. In this way the course of the marine mollusca might be traced laterally along the coast at the depth suited to their structure and habits. But life is not the only active force; the tidal wave and the great marine currents are in motion; the sea beats against the shore, and the detrital matter of the rocks is carried forward and deposited in new strata, by which the shallow water is made dry land, the deep water shallow, and the advancing mollusc is thus impelled, by the necessity of keeping at a definite depth, to pass from the surface of one bed to that of another; and if the general conditions remained the same, species may have thus lived over a space of time during which a long series of deposits were formed, and in consequence their fossil relics might be found through an extensive range of strata. This combined lateral and vertical extension requires time, and it may be therefore assumed, as demonstrated by Professor Forbes, that fossils which have the greatest vertical range, or have existed for the longest time, have also had the greatest extension in space.

Heat is the other great regulating cause which confines the progression of land animals to narrow limits. If fitted to a temperate climate, they must as they advance southward seek it on higher ground; and as the mountains of the earth are comparatively small, the range is limited and the extension soon stopped. In marine animals the case is varied, as will be understood by referring to the conditions of temperature in the ocean. It has been stated that the temperature of the earth increases in proportion to the depth below its surface: in the sea it is the reverse, as the temperature *decreases* with the depth, even at the tropics, until it has arrived at a very little above 32°. This to many will appear a contradiction, but it is not so: the outer crust of the earth is cooled on dry land by radiation or by radiation and transmission on land

covered by sea; but the passage of heat is slow through the earthy materials of the upper crust, whilst it is rapid through the aqueous covering; and it is therefore quite accordant with the laws of nature that the earth at the bottom of a sea many miles deep should be icy cold, whilst at a similar depth in the solid matter of the earth the heat would be sufficient to melt iron. Even in the tropics, as the sun's rays act but feebly on the water, and can have very little heating effect on the ground at great depths, the temperature would not exceed the mean temperature of the place, even if no interchange of water took place, except from below upwards, and *vice versâ:* but this is not the case, as water of a mean lower temperature will gradually move from north to south, until a general mean temperature has been attained by the ocean except in that merely superficial portion which is subject to the local influences of heated land, a portion which is deeper as it is nearer to the tropical or more heated regions. The very careful experiments of M. Ch. Martins in the corvette *La Recherche* are perhaps the most interesting on record. They were made in the Polar Seas, in the months of July and August of the years 1838-9, and extended to the depth of 870 mètres (2784 feet), giving a uniform decrease of $1\frac{1}{4}°$ Fah. for 320 feet, or ·69 cent. for 100 mètres, the final temperature arrived at being very nearly 32°. Parry and James Ross found the temperature lower, as it was only $28\frac{1}{2}°$ at the depth of 2304 feet in July, 1827. The equalization of temperature is further assisted by the flow of the heated equatorial waters towards the Pole, as is seen in the Gulf Stream, which, notwithstanding the doubts entertained by some on the subject, is traceable, according to M. Martins, to the North Cape. This uniformly low temperature of the depths of the ocean materially restrains the dispersion of animals suited to a high, and favours that of animals suited to a low temperature; and therefore explains many of those anomalies which occur in the habitats both of recent and fossil species. But the bottom of the ocean is not only altered by the deposition of fresh mineral matter; it is sub-

ject to all the disturbances of elevating forces, and it is therefore highly probable that the progression of animal life is stopped at one point by an elevation of the bottom which brings it within the influence of a temperature destructive of the organisms then living upon it, and at another promoted by a depression of the bottom, or *vice versâ;* and in this way various modifications of the groups of organic beings, and many abrupt terminations of them, must have been effected at all periods of the earth's history. These principles serve as a guide in investigating the topography of the ancient world; and, as pressure, independent of temperature, acts as a limiting force, it cannot be supposed that even the mollusca could be distributed without the aid of banks or shoals to preserve a suitable depth; or that the mammalia could have spread over the earth without a continuity of land, as air is essential to the preservation of their life. The development of the earlier fossiliferous strata implies therefore a continuity of the ancient shoals of those epochs, and it hence appears that Australia was, to a certain extent, connected with Europe at the epoch of the carboniferous deposits; or, ascending to newer deposits, analogies between the past and present creations are found in the oolites of Europe in the relics of marsupial animals, in the remains of fishes analogous to the Port Jackson cestracion, and in the remarkable genus trigonia, which still exists in Australia. This recurrence in Australia of a zoological type characteristic of the Oolitic period renders it probable that Australia and Europe were then connected by dry land, as in the carboniferous period they were by shoals; or may it not be possible that some of the mollusca and plants of the carboniferous epoch, which are associated with oolitic plants in the Australian coal field, arrived there by combined lateral and vertical extension at a geological epoch posterior to that of the coal formation of Europe? In the tertiary periods, or those immediately antecedent to the present, many examples may be traced of continuity of land now no longer existing; and Geology and Palæontology become guides to interpret the great changes

which have taken place at successive epochs, and to represent, as it were, the various phases of the globe amidst all its changes, clearing away those clouds of uncertainty and that confusion which had before baffled the student of nature, and interfered with his perception of truth.

CHAPTER VI.

General and Practical Remarks on Geological Formations.

In studying a geological formation, by which term is understood a representation of the mineral and organic conditions of the earth at some former epoch, the observer will meet with evidences of each description of formative process, the natural history of the earth implying an investigation of the changes both mineral and organic of each successive epoch. To express the relation between eruptive, metamorphic, and sedimentary rocks, a compound nomenclature, representing at once the epoch of original deposition and that of metamorphism, &c., has been proposed by Sir C. Lyell, as Ante-Cambrian carboniferous metamorphic strata, triasic oolitic metamorphic strata, &c., by which is meant that the strata were respectively deposited prior to the Cambrian, and during the triasic, but reduced to their metamorphic condition by forces acting during the carboniferous epoch in the first place, and the oolitic in the second; and in like manner there may be Ante-Cambrian plutonic, Silurian plutonic, carboniferous plutonic, triasic, oolitic, cretaceous plutonic, &c.; or Silurian volcanic, carboniferous volcanic, triasic, &c., up to the volcanic rocks still forming; and though it is difficult in very many cases to determine with certainty the actual epoch of the original condition, or of the metamorphic change, of the crystalline schists, and also of the upheaving and apparent partial eruptions of the plutonic rocks, or even of the cruptions of volcanic rocks, it must be admitted that the proposed nomenclature is correct in principle.

From a careful comparative study of the zoology and phytology of successive epochs of the earth's history, as displayed by organic relics formed in the mineral deposits, Geologists have established a certain number of distinct formations, each of which is characterized by its own animals and plants, and which are exhibited in a descending order in the accompanying Table.

Table of Comparative Thickness of Fossiliferous Strata or Formations.

Class.	Order.	Group. Marine.	Group. Fresh-water.	Germany, by Cotta. Feet.	England, by Phillips and others.
	Recent. Post-Pliocene, or Glacial.	Erratics. Gravel, sand, and mud.		100	
Tertiary.	Pliocene, old and new.	Marine preponderating.	Associated with Fresh-water.	80	1248
	Miocene. Eocene.			300	99
				Total . . . 380	1347
Secondary.	Cretaceons, excluding Wealden, which belongs to the next order.	Marine.		1800	1080
	Wealden.		Fresh-water.	Westphalia 600 Saxony 30	900
	Oolita, including Jura Limestone.	Marine.		400	1350
	Lias.			200	
	Trias, or new Red Sandstone.	Marine.		1500	900
	Permian, including Magnesian Limestone and red Conglomerate.	Marine.		1650	300
	Carboniferous, without old Red Sandstone.	Mixed marine and	Fresh-water.	600	2100 to 3000
	Devonian, or old Red Sandstone.	Marine.	Fresh-water deposits recently discovered.	From 150 to 10,000 Total . . . 16,750	Variable many thousand.
Primary.	Silurian. Cambrian.	Marine.	-	Cotta unites these in one formation. Total 6000	Many thousand feet.

According therefore to Cotta, the total thickness of stratified fossiliferous deposits is 22,750 feet, or about 4½ miles, exclusive of the variable and uncertain deposits of the existing

period; but such estimates are only very rough approximations, as the thickness of each deposit may be expected to vary in every locality, and to undergo very material modifications both in the character and proportions of its several parts.

In the remarks on these formations, the ascending order will be followed, the lowest recognized strata being first noticed, and each successive formation, growing as it were one out of the other, will be considered in the order of its occurrence.

CAMBRIAN, THE EARLIEST KNOWN FOSSIL DEPOSIT.

This term has been applied by Professor Sedgwick to stratified rocks which occur in Cumberland, North Wales, and other places, under the decidedly Silurian strata, and are for the most part slaty and without fossils. They contain but a small proportion of lime, and their fossils being local and rare, sufficient evidence has not been obtained for placing them in a zoological order distinct from that of the Silurian. The apparent thickness of the slaty and gritty beds is considerable, but this is due to contortions, by which the same beds are made to appear several times successively in the same section. The prevalence of the slaty character shows that the progress of formation has not been varied by much original disturbance, and the thickness of its beds indicates the probability of some portion having been a deep-sea, or rather semi-pelagic deposit. The Cambrian is now considered a marked group in the Silurian, and as the Cambrian group placed at the base of that system.

SILURIAN.

This formation, since the publication of the splendid work of Murchison, has attracted the attention of all Geologists; and as it exhibits the relics of organic beings in great abundance, and of very peculiar forms, has been rescued from the formerly obscure regions of the grauwacke, and reduced to light and order by the discoveries and research of Sir R.

Murchison and his followers. The lower group of this order includes the Llandeilo flags, or micaceous slaty grits, and above them the Caradoc sandstone. The next in order ascending is the Wenlock group, consisting of a deep bed of shale, surmounted by a bed of limestone; and the third or upper, the Ludlow, comprising the lower Ludlow shale, the Aymestry limestone, and the upper Ludlow, a calcareous grit or sandstone. In England these groups follow each other in actual sequence of superposition, and are distinct in order of time; but in other regions the sequence may be varied in conformity to the laws of geological deposit: whilst, therefore, in Norway and Sweden there is a partial similarity in lithological character, and the conditions of deposit have been nearly the same, limestone has been much more developed in many parts of North America, and the conditions of deposit have been different.

In the combined Cambrian and Silurian formation the earth first exhibits traces of life, and we find the remains of fishes strange in form, but high in organization, such as the genera onchus and plectrodus, many mollusca, including peculiar forms of the brachiopoda and cephalopoda; very characteristic crustacea, belonging to the extensive family of trilobites, which, beginning to exist at this early epoch, flourished in number both of species and individuals, and then rapidly passed away, the family being traced no further than the carboniferous order; radiata, rare; zoophyta, less abundant than in succeeding orders, but exhibiting some peculiar forms. In respect to the conditions of deposit, it may be observed, that though the extensive limestone strata of this epoch, adjacent to the great lakes of America, were probably pelagic (the large orthoceræ and many brachiopoda having been well suited for deep seas), and formed, like the mountain limestone of the carboniferous system, and even like some deposits of the recent epoch, by an accumulation of the remains of testacea, or, on the temporary cessation of the influx of mud, by the growth of corals suited to such habitats, the evidence afforded by the fossils of England

and Ireland, particularly by the trilobites, the many species of nucula, and even it may be added by the fishes which were probably fitted to grovel in the mud, indicates local deposits of mud and sand in moderate and sometimes shallow depths.

The invertebrate fossils which have not hitherto been discovered in any more recent deposit, excepting in some instances in the Devonian, are graptolites, which are zoophytes related to the pennatula; chain coral, catenipora escharoides; many genera of trilobites, such as remopleurides, phacops, calymene, asaphus, ampyx, trinucleus, harpes, brontes, and several others; of brachiopoda, the genus pentamerus; of cephalopoda, the genera phragmoceras and lituites, &c., the great development of the nautiloid type of mollusca being a remarkable fact in this early portion of the earth's history; but it is impossible to notice here all the peculiarities of the many remarkable fossils of this formation without entering largely into their natural history; nor is it necessary to state what fossils characterize the subdivisions or groups of the formation, as it is enough, in a practical point of view, to be able to recognize the existence of the formation itself; which is of much importance, as it lies below the great carboniferous system on the one hand, and on the other overlies a series of metamorphic rocks, embracing the useful deposits of various descriptions of slate and other building stones.

In the classification of M. D'Orbigny the Silurian system is divided thus :—

$$\text{Silurian} \begin{cases} \text{B. Murchisonian, or upper.} \\ \text{A. Silurian, or lower:} \end{cases}$$

and he enumerates 356 species of mollusca and 61 of radiata in the upper, and 375 species of mollusca and 52 of radiata in the lower division.

Many of the schistose beds yield good flags and slates.

Besides the various localities of Europe and America, the formation has been noticed at the Falkland Islands, and in South America. In Russia and in North America this formation is frequently exhibited in the actual state of its original

deposition, occurring in widely-extended horizontal beds abounding in fossils.

DEVONIAN, OR OLD RED SANDSTONE.

This order, so long known under the name old red sandstone —a term nearly as obscure as that of grauwacke — has, by the researches of Professor Sedgwick, Sir R. J. Murchison, Sir H. De la Beche, and Messrs. Phillips and Lonsdale, been raised to the rank of a distinct fossiliferous formation. Viewed as sandstone and conglomerate in the light of drift, it appeared difficult to connect it with the limestones of Devonshire; but when similar limestones were found on the Continent in similar positions, the limestone of the Eifel being thus placed, this difficulty was removed, and the formation was found to embrace the usual assemblage of argillaceous, sandy, and calcareous strata. In Scotland, and on the borders of Wales, it occurs in the form of a red sandstone and conglomerate, associated with shale and marl; the conglomerate and sandstone at the top, the variegated marls and impure concretionary limestone (cornstone) in the centre, and variegated micaceous or quartzose sandstone splitting into tiles (tilestone) below. In the North of Scotland many peculiar forms of fishes have been found in the lower division, whilst in the upper, comprising the belt of yellow sandstone, appears the genus holoptychus, which extends into the carboniferous order. Were this portion alone of the system studied, it would appear to be connected with the carboniferous rather than with the Silurian, and it is so placed by Cotta; but when the Devonshire and Cornwall strata are examined, and compared with those of the Eifel, the presence of species common to the Devonian and Silurian on the one hand, and to the Devonian and carboniferous on the other, impress upon them a different character. In consequence of this mixed distribution of fossils, Professor Phillips has proposed to embrace under the general term palæozoic, the Cambrian and Silurian as the lower palæozoic, the Devonian as the middle palæozoic, and the carboniferous as the upper palæozoic, to

which Sir R. Murchison has added the permian, including the magnesian limestone. Of 275 species in the Devonian strata of Devon and Cornwall, Professor Phillips states that 25 have been found in the lower division in England, 51 in the upper division in England, and 57 in the Eifel and Bensberg.

The very dilapidated condition of many of the fossils of this formation shows that they have been drifted into the deposit; the trilobites and many other fossils of the Silurian epoch described by Professor Phillips being generally in a shattered state: if then these fossils, and many of the zoophytes, &c., were brought in by drift, it is very possible that they were living elsewhere at the time of the deposition of the Devonian strata, and that the actual zoological relations between the Silurian and the lower Devonian are closer than would be inferred from such fragments alone. Professor Phillips seems to adopt this opinion, that there is a considerable analogy between the lower Devonian and the Silurian on the one hand, and on the other between the upper Devonian and the carboniferous. Cotta classes the Eifel beds with the Silurian; but if Silurian, they occupy a higher position in the series than any of our English or Irish beds, and must therefore be parallel, as shown by our English authors, with the lower Devonian. M. D'Orbigny states the number of mollusca at 1054, and of radiata at 146,—numbers so great when compared to the more decided formations below and above, as to strengthen the belief that many of them are extraneous.

In referring to the use of fossil evidence it should therefore be remembered, that as any fossil species of an early epoch may be continued upwards, or drifted into more recent formations, the appearance of a small number of such fossils cannot be considered sufficient evidence to place the strata containing them in the older formation, unless supported by the general grouping and arrangement, under the same petrographic characters; whilst on the contrary, the appearance, in any bed, of fossils characteristic of a more recent formation, must always be

strong presumptive evidence against its antiquity. Dr. Mantell and Capt. Brickenden have announced the discovery in the Elgin sandstone (considered a portion of this system) of a new reptile, in which the characters of lizards and frogs are blended together, and Dr. Mantell has named it *Telerpeton Elginense*. Professor Forbes has also announced the discovery of fresh-water shells and plants in the old red sandstone of Knocktopher, county Kilkenny, Ireland; and these two facts of the existence of air-breathing reptiles and of fresh-water animals and plants at so remote an epoch, are singularly confirmatory of the analogies between the past and present states of the world.

Practically, many beds of this formation, especially of the yellow sandstone, are excellent building stones; whilst the decomposition of its marly beds produces a rich productive soil. The limestones are valuable both for building stone and lime. In Russia, south of Petersburg, a large area, formerly supposed to belong to the new red sandstone, is of this geological age, though abounding in saliferous and gypseous beds;—being another proof that salt deposits have, in very similar circumstances, been formed at various geological epochs. The determination of this formation is important, as it generally underlies the coal, whilst in Spain coal-bearing strata are associated with it.

CARBONIFEROUS.

This formation, so important in its economic bearings, is a vast assemblage of calcareous, arenaceous, and argillaceous strata. Of these the great masses of limestone were probably formed in deep seas, and the coal shales either in estuaries or lakes, so that where the limestone division prevails, the shales may be expected to diminish, and the estuary character being lost, the coal will become less abundant, as in Ireland, where it is comparatively scarce.

The great limestone deposit which forms the basis of this system has been called the mountain limestone, and is charac-

terized by many peculiar fossils: in the South-west of England, in Somersetshire and South Wales, it is strongly marked, and is separated from the coal measures above by a thick deposit of arenaceous strata; but in the North of England the coal descends into the millstone grit, and even alternates with the upper beds of the mountain limestone; and in Scotland, this mixture of marine strata with those containing coal is still more marked. In Ireland, many of the masses of the mountain limestone are separated into distinct beds by shale, not associated with coal, which was probably also deposited in tolerably deep water, as in the Mediterranean, where the coral living at the bottom of its waters is frequently covered over by mud moved along by the currents.

The presence not merely of a vast variety of terrestrial plants in the coal shales and grits, but in some cases of fresh-water fossils, has led to the belief that some of these deposits were lacustrine; but whether formed in actual lakes, or at the mouths of rivers which, when occasionally dammed up, became for the time lakes, cannot be determined. The fossils of this formation are very characteristic: in the plants, so rich in forms which resemble the tree ferns of the tropics, there is evidence of a climate like that of our most Southern regions, and the analogy is supported by a great abundance of sauroid fishes, and of cartilaginous fishes of the families of squalidæ and raiidæ. The crinoids, or lily-shaped animals, are largely developed; as are the corals, many of which are lamelliferous, as in coral reefs now forming: and in investigating this portion of the zoology of the formation, it is desirable to study the habitats of corals, many of which are confined to reefs whilst others live in shallow water on the coast and are frequently enveloped in mud, and thus to trace out the peculiar condition of the sea-bottom of that epoch. Of brachiopodous molluscs, the genera productus and spirifer abound.

Coal is the product of ancient vegetation entombed in mud and sand, and in the course of ages reduced to its present state by chemical change; but consistently with this conclusion it

might be assumed either that the plants grew where the coal now exists, or that they were washed down into estuaries, and there accumulated, or that coal is the product of ancient bog or peat moss,—an opinion supported by microscopic investigation. It is highly probable that each of these theories is correct in certain localities, and the alternations which must have taken place in either case are very remarkable: for example, in the North of England the total thickness of the coal-bearing strata may be estimated at 3000 feet, whereas the coal itself is arranged in many layers or seams, the total thickness of which does not exceed 60′, whilst the thickness of the seams varies from a few inches to 6′ or 7′. In the Newcastle district, counting the minute seams, there are forty layers. At Dudley there are eleven, of which one is 30′ thick. In South Wales there are twenty-three beds exceeding 1′ 6″ in thickness, besides many others, the total thickness of workable coal being 95′, equal in mass to many hundred million tons of coal. At Mons there are 115 workable seams, few of which exceed 3′ thick. Besides the Irish and Scotch coal fields, England and Wales possess the following coal basins: Northumberland and Durham, Yorkshire, Staffordshire, Lancashire, Whitehaven, Warwickshire, Shropshire including Coalbrook Dale, North Wales, South Wales, some of which may be subdivided into other basins.

These masses of vegetable matter, composed of the remains of plants which have long since passed from the living world, the greater proportion belonging to the order of ferns and others being giant mosses and cellular plants, exhibit peculiar conditions of organic life. Some of these conditions have been repeated, though in a fainter degree, at subsequent epochs, and given rise to limited carbonaceous deposits; but as the various changes, physical and organic, effected on the earth's crust, advance towards the present state of things, an approximation to the conditions now observable, or a recession from those which once so greatly promoted the growth of succulent plants, is in accordance with the laws of nature. As the effect of a diminution of central heat became locally perceptible, suc-

cessive portions of the earth were fitted, though in a varying degree, for the support of such plants, and partial deposits therefore appear at various epochs; and it may be added, that when the Polar regions were thus brought to a proper temperature, they were, from the deficiency of solar heat, better fitted for such vegetation, the climate being more equable and less affected by the scorching effects of the sun's rays than in Southern regions. The seams are sometimes extended over a wide space, but the general character of a coal deposit is that of a basin in which the phenomenon of faults is strikingly exhibited, the seams being sometimes thrown up or down several hundred feet; some faults being accompanied or caused by dykes, whilst in others the cause of dislocation and of vertical slips is not visible on the surface. The knowledge of the various forms of faults, and of the direction in which a suddenly lost seam should be sought, constitutes one of the most difficult points in mining science.

The following Table from Dr. Ure gives the quantities of coal shipped from the several ports in England, Wales, Scotland, and Ireland, in 1836 and 1837, and there has since been a vast increase, as it appears in Taylor's Tables ('Statistics of Coal,' p. 260) that 11,254,750 tons were shipped in 1845.

	1836.	1837.	Increase.
	Tons.	Tons.	
England and Wales	6,757,937	7,570,254	812,317 or 12·02 per cent.
Scotland	624,308	626,532	2,224 or 0·36 „
Ireland	7,027	7,515	488 or 6·94 „
Total . . .	7,389,272	8,204,301	815,029 or 11·03 per cent.

In Fuller's time (1661), 200,000 chaldrons were imported annually into London, but now the consumption is nearly 3,500,000 tons, which is brought into port in about 9700 ships. The annual quantity raised was estimated at 15,500,000 tons by Mr. Taylor, and Durham and Northumberland, he considered, could have met that demand for 1700 years. Mr. R. C. Taylor estimates the whole British production in 1845 at nearly 35,000,000 tons per annum. The area of the coal measures of

Great Britain and Ireland is 11,859 square miles, or 7,589,760 acres, or about one-tenth of the total area; and there are in all 51 coal fields. The French Mining Reports state that coal is raised in thirty departments of France, in which 258 mines are in operation, and 21,913 workmen employed. In 1814, the quantity raised was 665,000 tons; in 1825, the quantity had doubled; in 1832, the produce was 1,600,000 tons; in 1836, it amounted to 2,500,000, and it is now more than 4,000,000 tons.

Cotta gave in 1839 a statement of the coal produced in the several coal districts of Europe, which is useful for comparison, though requiring much correction, as the produce of Belgium was in 1845 about 5,000,000 tons.

	Tons.		Tons.
In England . .	20,769,231	Brought forward	30,753,233
Belgium . . .	5,215,385	In Sweden and Norway	28,293
France . . .	2,215,385	Hanover . . .	21,646
Prussia . . .	1,569,231	Spain	18,462
Russia . . .	738,461	Both Hesse . .	15,231
Austria w[th] Bohemia	184,616	Sardinia . . .	4,662
Bavaria . . .	32,308	Weimar . . .	1,939
Saxony . . .	28,616	Portugal . . .	415
Carried forward	30,753,233	Total . . .	30,843,881

Mr. R. C. Taylor states the production of the United States as about 4,500,000 tons, but this affords an imperfect measure of the power of production, as the area of the Alleghany coal field is 65,300 square miles, or nearly one-fifth of the total area of the States in which it is situated. Dumas gave, in 1828, the following values of the coal produced:

	Francs.		£
England	90,000,000	=	3,562,500
Low Countries, including Rhenish Provinces and Luxemburg	37,000,000	=	1,464,583
France	12,000,000	=	475,000
Russia, Silesia	3,600,000	=	135,000
Hanover and German Confederation .	3,600,000	=	135,000
Total			5,772,083

The coal produced by the British coal fields more than doubles the quantity raised in the collieries of the rest of Europe; and the gross value of the collieries of Great Britain and Ireland cannot be estimated at less than £9,000,000 sterling.

But this is not the only valuable product of the formation. Beds of argillaceous carbonate of iron, or clay ironstone, which is the iron ore principally used in the British Isles, are associated with the coal shales, thus putting in contact with each other the mineral ore and the fuel for smelting it. In 1826, the quantity of pig or cast iron produced was between 600,000 and 700,000 tons; and in 1846, 2,214,000, being equivalent in value to £8,856,000, at £4 per ton sterling. In France, the number of establishments in 1836 was 894, and of workmen 15,738, the product being 303,739 tons of pig iron; and in 1845, 448,900 tons of pig or cast metal were produced and manufactured into 342,200 tons of bar iron, which, at about £6 per ton, would be worth two millions sterling; and as the manufacture of pig into bar iron is so closely connected with the first process of smelting, that the higher value of this product may be assumed instead of that of pig iron in estimating the importance of the iron manufacture,—how great must be the wealth produced by this homely but most essential metal, even in this early stage. In France, that beautiful association of the iron ore with coal, which distinguishes the British coal fields, exists only very imperfectly, so that a large portion of the iron is smelted by wood or charcoal. In Belgium, which as a coal country ranks in Europe next to England, 150,000 tons of iron were produced in 1845, and most summer travellers know the busy activity of the iron works of Liege, where 4200 men are employed night and day, and are aided by eleven steam engines with an aggregate force of 500 horse-power.

Nor are these the only resources of the formation. In England the mountain limestone, which exhibits in its layers of silicious or chert concretions a strong analogy to the subsequent pelagic deposit of the chalk, is the source of much mineral

wealth, and produces more than one-half of its lead. The proportion due to this formation may be assumed as 30,000 tons, equivalent to about £500,000 sterling; so that, from this formation alone, mineral wealth is annually produced in Great Britain to the amount of nearly £19,000,000 sterling; whilst, in addition to this direct production, its indirect importance as affording the means of smelting the ores of other metals, such as copper and zinc, is forcibly illustrated by the extensive works of Swansea, to which copper ores are brought from all quarters of the globe, and the value of the lime, and marbles or other building stones, produced from the limestone, and of the excellent building stone which is obtained from many of its grits, as in the neighbourhood of Glasgow, the beauty of that city being due to the proximity of such excellent materials, is very great. If the mind passing from the simple value of the materials themselves can realize the vast results proceeding from coal and iron in the use of machinery in manufactories and railways, it discovers in the possession of such large and productive coal formations, the source and foundation of the commercial, and, as its consequence, the political greatness of Great Britain.

Great Britain has in her colonial possessions of New Holland another coal formation, which has been supposed to belong to a more recent epoch, though it is highly probable that the peculiarity of some of the plants only implies a commencement of that isolation of type which now distinguishes that country; and the coal of the East Indies is also supposed to be more recent than the true coal formation. China and Japan are supposed to possess extensive deposits, and coal occurs in Borneo and Labuan. In America a formation both of blind and bituminous coal, within the limits of the United States, greatly exceeds in extent our British coal fields; and in our own colonies of New Brunswick, Nova Scotia, Cape Breton, Prince Edward's Island, and Newfoundland, there is an extensive coal formation. In New Zealand coal of good quality has also been found; and there is reason to believe that in our South African possessions

a coal formation of considerable extent exists in Port Natal. The preceding is but a faint and imperfect sketch of the lateral distribution of this most valuable mineral formation, as it has been impossible in so brief a space even to notice some of its deposits, such, for example, as the Spanish coal district of Asturias; but enough has been said to show how large a portion of the earth's surface had been at this epoch clothed with a tropical vegetation. The disturbances which have affected the crust of the earth either during or subsequent to the formation are not only exhibited in the great faults of the coal beds, but in the remarkable difference of position in which such beds occur, many of the seams at Newcastle being worked under the sea, whilst at Chipo, which rises above the Plain of Santa Fé de Bogota, coal is found at 8000 feet above the sea, and at Huanoco at 12,800 feet, or at the limits of eternal snow.

It was supposed only recently that reptiles first existed at this epoch, exhibiting in the Archegosaurus a monstrous form between the toad and lizard, the body of the former being combined with the jaws and teeth of a saurian, and it was further assumed from the discovery of carboniferous reptiles that the future discovery of the remains of birds and mammals in that formation would not be impossible; but it does not appear that the one discovery renders the other more probable, as the peculiar blending of the saurian and batrachian types in one indicates a more than usual development of reptilian organization calculated to combine in one great class the functions spread over many classes in the more balanced and perfect organic system of the existing world. The discovery of three species of the genus Archegosaurus and of the genus Apateon carried back the origin of reptile life from the permian to the carboniferous epoch, but it has now been pushed still further back to the Devonian by Capt. Brickenden and Dr. Mantell, thus proving the existence of dry land and of air-breathing animals of a similarly mixed type between the lizard and the frog anterior to the coal deposits.

PERMIAN, INCLUDING MAGNESIAN LIMESTONE.

This formation, including its underlying red conglomerates, sandstones, and marls, is important, as it overlies the carboniferous. In the South-west of England its strata are unconformable to those of the carboniferous system, whilst in the North-east they are conformable to and seem to form part of them; but as in all formations, cases of this partial conformability between the upper and lower will occur, according as the disturbing movements are more or less extensive or local, it is necessary to determine great geological divisions from a general and not from a local examination. Though the sandstones strongly resemble the new red sandstone, the fossils of this formation closely approximate to the carboniferous, the genera productus and spirifer of the brachiopoda occurring in both; as well as the genus palæoniscus of fishes, a remarkable genus, which however extended upwards into the new red sandstone, where the palæoniscus catopterus occurs in profusion, associated with posidonomya minuta, in a small patch or pool of the sandstone and marls of Rhone Hill, county Tyrone. In the opposite direction, spirifer undulatus (Sow.), supposed a characteristic species of the magnesian limestone, occurs in Ireland in beds which are overlaid by apparently well-marked carboniferous limestone. On the Continent, the name 'rothes todtliegendes' has been given to the lower red conglomerate, to distinguish it from the white grits which immediately underlie the kupferschiefer or copper slate and sometimes contain copper ore, which the red-*dead*-lyer does not. In England, there is neither the copper slate nor the white grit, and the lower red sandstone and conglomerate are placed by Cotta in the carboniferous system which immediately underlies the magnesian limestone. In the South-west of England, drift or conglomerate beds prevail which possess the peculiarity of a dolomitic or magnesian limestone paste; in the North-east, a yellow magnesian limestone, passing upwards and downwards into marl slate and marl with gypsum. On

the Continent, the zechstein is a dense though sometimes porous, grey, generally fetid magnesian limestone, connected upwards with marls containing many extraneous substances, such as ironstone, gypsum, and rock salt, thus approaching to the character of the true new red. The copper slate of Mansfield has a thickness varying from 1½ ft. to 2 feet, and is worked in numerous establishments by a most difficult process, called there krummhölzerarbeit, or crooked-stick work, the miners crawling and working in low cavities, only 18 or 20 inches high, lying upon their sides, and being supported by pieces of bent timber or crooked sticks. In England, the formation is practically important from the excellent building stone which some of the magnesian beds afford, the tint being specially favourable for Gothic buildings. York and Beverley Minsters are favourable examples of the stone, but its durability varies according as the more purely magnesian limestone or the gritty beds have been used. This stone has been selected for the New Palace of Westminster as the best building stone of England.

It was long thought that nothing but deteriorated coal would be found under the magnesian limestone; but this error, doubtless proceeding from a belief that the magnesian limestone, like crystalline dolomites, had been formed from metamorphic action, has now been dispelled, and the magnificent collieries of Hetton in South Durham have laid open the coal seams by piercing through the magnesian limestone. Mr. W. King has illustrated the formation by his recent monograph of permian fossils. This monograph exhibits some cases of approximation to the subsequent trias, but more of a close resemblance to the carboniferous; and it may also be stated that the flora of the permian approximates more closely to that of the carboniferous than of the trias, though M. Adolphe Brongniart has pointed out great differences in its several divisions. In Russia, the permian system is fully developed, and combining all forms of deposit, is manifestly entitled to the rank of a distinct formation. Mr. King has described 277 species

of plants and animals, and very recently two remarkable fishes from the Russian strata have been described by Fischer,—the Ommotolampes Eichwaldi, which is 3 feet long, and covered by bony shields, which were at first mistaken for tortoise-shell, and Trachelocanthus Stschesrovskii, which has a spine in its throat turned backwards,—both of which, from their affinities, were probably fresh-water fishes.

NEW RED SANDSTONE, OR TRIAS.

This formation, from the prevalence of a variegated character in its sandstones and marls, has been sometimes called 'poikilitic.' On the Continent, where its several members are better developed than in England, it has received the name of 'trias,' as divisible into three great sections. The lowest of these is the 'bunter sandstein,' or variegated sandstone, which is distinguished by greenish stripes and spots, and contains clay galls; it is associated both above and below with variegated red and green marls, containing both laminated and fibrous gypsum, and rock salt. The muschelkalk, or central division, is deficient in England, and as gypsum and rock salt occur on the Continent in marls, both of the upper and lower division, it is difficult to decide generally whether our salt-bearing strata do or do not belong to the more decided sandstones and conglomerates which underlie them. The white sandstone of the Vosges, supposed to belong to the lower or variegated division, is placed by Sir R. Murchison in the permian: it is a valuable building stone.

In Thuringia and Swabia the muschelkalk division is fully developed; the limestone (which is occasionally dolomitic) occurring under several forms or varieties which alternate with marls and clays sometimes containing gypsum and rock salt.

In the upper division or keuper, marls and clays prevail, though still associated with sandstones. Gypsum and rock salt still occur, and sometimes an impure coal. As fossils are extremely rare in the sandstone divisions, it was scarcely possible to allocate to their proper place in this triple system

the English beds; but the fossils of a dark marly stratum called the 'bone-bed,' which occurs at Axmouth, and on the banks of the Severn in Gloucestershire, are characteristic either of the keuper or muschelkalk; they are, Hybodus plicatilis, Saurichthys apicalis, Gyrolepis tenuistriatus, G. Albertii,—of which it is very remarkable that Saurichthys apicalis, Gyrolepis Albertii, G. tenuistriatus, have been also found in a seam of calcareous grit connected with black shale in an equally local deposit on the face of Ben Evenagh, at Lisnagrib, county of Derry, the Acrodus minimus, another muschelkalk fossil, being there added to the list. It may therefore be reasonably inferred that though the muschelkalk is not fully developed in the British Islands, two members of the series, with a trace of the other, are certainly present.

The remarkable foot-prints of an animal, to which the name chirotherium was given, should be here noticed. Various conjectures as to their nature were hazarded, but Mr. Owen has proved that they were formed by the animal which he had previously named labyrinthodon from the nature of its teeth, and which belongs to the batrachian order, or is a gigantic frog. It will be observed that in respect to this organic form an analogy of type continues through the Devonian, the carboniferous, the permian, and the triasic formations. The genus ammonites of the cephalopodous molluscs first appears here; and in the flora as well as fauna there is a striking difference from the underlying strata, the species of forty-seven genera noted by Professor Bronn being quite distinct. The type of decapodous crustacea, to which our crab and lobster belong, first appears, and footsteps of supposed wading birds have been observed in America. It was announced some years ago that the remains of mammals had been discovered in this formation in Wurtemberg, and this discovery has been confirmed by the detailed description of the fossil bones by M. Jäeger, who considers them to belong to an animal of the marsupial type, allied to the didelphis; and if this be a correct

determination, it is another example of the very early appearance of this now almost isolated type on the earth.

In England, this formation is the depository of rock salt. In Cheshire, the alternating beds of red and green marl with gypsum and rock salt sometimes exceed 600 feet in thickness; and at Northwich, the two beds of salt are at least 60 feet in thickness, and extend laterally for 1½ mile. In Ireland gypsum prevails more than salt; but even there, on the line between Belfast and Carrickfergus, there is reason to believe that salt may be found. And generally the curious connection of sulphate of lime with chloride of sodium deserves attention, as affording a probable indication of the occurrence of salt in other formations, and some clue to the laws which regulated its deposition. The average quantity of salt manufactured in Cheshire may be stated at about 250,000 tons annually. The celebrated salt mines of Wieliczka, in Galicia, belong to the cretaceous formation.

LIAS ORDER.

In this formation argillaceous matter or clay preponderates, being associated with argillaceous limestone; marl, sandy marl, and sandstone, and it is remarkable as having been the age of marine reptilia; for although the genus ichthyosaurus first appeared in more ancient deposits, it seems to have here attained its full development, and was accompanied by the equally curious genus plesiosaurus. The existence of a marine saurian amidst the Gallapagos Islands, as noticed by Dr. Darwin, exemplifies the probable mode of existence of these vast animals, and the conformability of their habits with those of the crocodile. A curious genus of cephalopodous molluscs, the belemnite, first appears here, and the gryphæa, a genus of the family of oysters, is abundant, establishing by their presence the marine origin of the deposit, and confirming the fact that marine saurians were, at that early period, swimming in multitudes around the muddy shores of the then existing

land. The characteristic colour of the limestone, which sometimes in a section exhibits a riband-like arrangement amongst the argillaceous beds, is blue, but there is occasionally a white variety, whilst in some instances sandstone prevails over the limestone in the lower members; as for example, in Würtemberg, where sandstones of brownish and yellowish hues are associated with marls and limestones in the lower lias, the upper being composed of dark lias shale and limestone. The lias shale of Würtemberg is so rich in a species of the genus posidonomya, the P. Bronnii, that it has been called the posidonian shale; and the similar occurrence of that genus in shales of the carboniferous period, as well as in marls of the new red, is illustrative of the analogous character of all such deposits, Some thin beds of coal occur also in the shales, which, as well as the limestones, are strongly impregnated with bitumen, the product, most probably, of decomposing animal substances, such as fishes, &c., which abounded at the epoch of their deposition. Practically the sandstones, though liable to become ironshot or stained, are occasionally sufficiently firm to be used for building. The limestone is occasionally hydraulic, and the soil is generally fertile.

OOLITE OR JURA FORMATION.

The clays of the lias form the basis of the oolitic system, and in ascending into it, other argillaceous bands mark those changes in the conditions of deposit which are to be expected in every great formation, representing, as it must do, the variations of drift consequent on the changing direction of currents. These bands have, in England, led to a division of the oolites into lower oolite resting on the lias; the middle oolite resting on the Oxford clay, which separates it from the lower oolite; and the upper oolite resting on the Kimmeridge clay, which is between it and the middle oolite: but it must be evident that such clay bands, being merely the result of local causes, cannot be expected to occur universally, or to produce a similar division in all countries. On the Continent, the formation has

been divided into the upper and lower Jura, the upper being characterized by a light-coloured, whitish or yellowish limestone, which forms the great mass of the Jura Mountains, from which it has derived its name, and the lower consisting of roestone and dolomite, the latter penetrated by holes or cavities, and of sandstone, marl, and clay. The hornstone partings of the Jura limestone strongly resemble the flints of the chalk, and its surfaces exhibit very beautiful dendritic markings of oxide of manganese like those of the chalk of Ireland. The Bavarian Jura formation is remarkable for the numerous bone caverns of its dolomites, and for the celebrated lithographic stone of Solenhofen. The wooded hills of Pappenheim are composed of a regularly stratified limestone, arranged in thin horizontal beds. The stone is extraordinarily pure and dense, yellow or grey in colour, and, from the thinness and regularity of its layers, peculiarly fitted for lithography. The hills themselves are distinguished by their broken aspect and wall-like character, which makes them look like so many fortresses; and on entering the valleys, the ringing sound of the true lithographic stone, as it is broken up for use, is heard on all sides. The layers used for this purpose are from 1 to 4 inches thick, and when still thinner, or unfit by containing fossils for lithography, they become useful as roofing tiles, as door and window linings, as tables, &c., to which purposes they had been extensively applied long before the invention of lithography. These peculiarities of the physical features of the country, and of the mechanical characters of the stone, deserve to be remembered in looking out for good lithographic stone in other countries. The presence of large fossils is a great defect in lithographic stones, and veins also should be carefully avoided, as in printing they mark the drawing, however fine they may be, with white lines, and increase greatly the difficulty of reducing the surface to a uniform state. Of the English oolites the Stonesfield slate, lying at the base of the great oolite, a member of the lower division, is the most remarkable: it is a slightly oolitic limestone, and though only 6 feet

thick, abounds in fossils. With impressions of ferns and other terrestrial plants, the elytra of beetles, and the remains of saurian genera already noticed, occur those of the pterodactyl or flying lizard; and what is still more remarkable, the jaws of at least three species of mammiferous quadrupeds of the marsupial order,—partly allied to the opossum, and partly to the marsupial genus myrmecobius of Australia,—a singular analogy, at this early epoch, to a region still so widely distinct in its fauna from other parts of the world. In the lower division also occurs the Bath oolite, which is an excellent stone for the delicate mouldings of Gothic architecture, and is represented in France by the Caen stone, which was imported for the purpose by our early architects, as may be seen in the beautiful Temple Church. In the middle oolite is the 'coral rag,' so called from the continuous beds of corals of which it is composed, and which still retain the position in which they originally grew. In the upper oolite is the celebrated Portland stone, so well known for its beauty as a building stone.

Many parts of this system are distinguished by a profusion of some particular fossil, a fact which is always characteristic of a regular deposit, as distinguished from a drift: such, for example, were the great oolite, the surface of which is studded over with pear-encrinites, which were afterwards buried by the irruption of the Bradford clay, the clays of the upper oolite, with their oysters and gryphites (ostrea deltoidea and gryphæa virgula), the nerinæan limestone of the Jura, distinguished by the peculiar univalve genus nerinæa and the diceras limestone of the Alps, so called from the abundance of specimens of the very curious bivalve genus diceras.

In this formation the fossils generally mark a marine origin, but the frequent occurrence of fragments of wood, the coal beds and bituminous shale which enter into the system, the many impressions of plants and of insects, as in the calcareous slates of Stonesfield and Solenhofen, the abundance of saurians and of encrinites which may be considered more fitted for

shallow than for deep waters, and, above all, the actual discovery of land animals, which it is now known existed even in the trias, all concur in proving that the deposits were formed in the vicinity of land; and it is therefore a fitting precursor of the next formation, in which evidences of land and fresh water in connection with it are more decisive.

WEALDEN FORMATION.

This formation, remarkable for its fresh-water origin, is not entirely destitute of marine fossils, and it has therefore the character rather of an estuary than of an inland lake. On the Continent, it has been associated with the cretaceous system, and considered the equivalent of the Neocomien of the French. In England, the oolitic beds were first raised up quietly without any great disturbance, as is shown by the celebrated 'dirt-bed' of Portland, with its upright roots, which rests horizontally upon them, the roots even penetrating into the subjacent oolite; and then portions of the compound deposit were thrown out of the horizontal position, as appears in the section at Lulworth Cove. If the principal basin, in which these beds have been traced, extending at each end from France into England, be really continuous, the deposit, whether lacustrine or estuary, was very extensive, though much interrupted, formations of a different character being contemporaneously deposited within its area: but these are problems very difficult of solution, as it is almost impossible to represent to the mind the actual condition of the earth's surface in respect to land, sea, and river, at each successive epoch of its history, obscured as it must have been by the effects of reiterated changes and unceasing wear.

This vast lake or estuary being exposed to the action of the sea, the dry land bordering it, and islands within its precincts, were covered by the marine deposits of the cretaceous epoch, an operation which was aided by a depression of the land sufficient to permit deep sea deposits. Such wonderful oscillations are strongly contrasted with the comparative quiet which now

reigns on the earth; but they are learnt from geological investigations, just as the facts, the habits and opinions of past ages are from historic records; and we owe therefore to this science the knowledge we now possess of changes which must without it have been unknown to us. In England, where this formation is more extensively developed than in any other country, the well-known Purbeck limestone, distinguished by a profusion of fresh-water shells, forms its base. The beds of limestone are separated by marls, and the conjoint thickness is about 250 feet, a great depth for a fresh-water deposit. The Hastings sands with clays and calcareous grits succeed, and are about 400 feet thick, being equally extraordinary as a fresh-water drift; and the whole is covered by the Weald clay, with its thin beds of sand and shelly limestone, about 200 feet thick. This formation implies the existence for a long time of vast areas of fresh water, resembling those of North America, in which at this moment, from the continued wear of their banks, and depth of their bottom, which in some cases is below the level of the sea, extensive deposits must be forming. Mr. Robertson has proved the existence of Wealden beds at Brora, in Sutherlandshire, and advanced reasons for associating the Yorkshire oolitic coal also with this formation. The Neocomien beds, which French Geologists consider the equivalent of the Wealden, are marine deposits consisting of variously coloured sands, and of marls and clays characterized by peculiar fossils, amongst which especially Holaster complanatus, one of the Echinidæ, abounds. These beds are separated from the overlying greensand by French, and associated with them by English Geologists.

Similar fresh-water deposits can be traced in other countries; and it is evident therefore that a very large portion of Europe was once covered with fresh water. In Westphalia the Wealden is represented by a deposit 800 feet thick, consisting of sandstone and bituminous marl, with layers of coal and of ironstone and beds of limestone, the whole being characterized by fresh-water fossils. In Saxony, at Niederschöne, it is reduced to a

deposit 40 feet thick, of dark-coloured sandy shale and marl, which is sometimes bituminous, and contains traces of coal, with an abundance of vegetable remains. Amongst these fossil plants only one shell has hitherto been discovered, but that is a most characteristic one, belonging to the fresh-water genus anodonta, which is confined exclusively to muddy lakes and pools. The quadersandstein, or green-sand, overlies this deposit, and Cotta thinks it probable that the beds of that formation in Silesia, which contain coal and the remains of plants, should also be allotted to the Wealden. Amongst the numerous reptiles of this epoch appear tortoises of genera which now occur in the fresh water of tropical regions. The iguanodon, so called by its discoverer, Dr. Mantell, from its analogy with the living iguana, was a herbivorous reptile about 30 feet long, and appears to have abounded at this epoch, associated with the hylæosaurus, another gigantic saurian. The nature of the fossil plants, and the number and magnitude of the reptiles, show that the climate still continued tropical. The Purbeck limestone is well known as lumachella marble, the designation lumachella being derived from the Italian word lumaca, a snail, and applied to those varieties of limestone which, with a granular or marble structure, abound in fossils. Caution is required in the selection of this stone, as some of its beds easily disintegrate; and in all specifications for its supply a sample should be referred to, in order to insure the delivery of the proper kind; a remark which is applicable in various degrees to almost every building stone. The sandstones, which are not durable, wear into very picturesque scenery, as about Tunbridge. The clays produce a strong soil, as in the rich district of the Weald of Kent.

Before quitting this last member of the oolitic series, it is right to make a few general observations on the facts which it exhibits. The æra of the oolites was one in which the reptile type was most highly developed; and reptiles, from the first appearance of the type in the old red sandstone, or probably in the Silurian, to its condition of highest development

in the oolites, appear to have been designed to fulfil the functions of other classes of animals. Hence there is a variation in the anatomical structure calculated to embrace forms and functions now appropriated to other animals. In Australia this extension of one type so as to represent several classes of animals is found in the marsupials, some of which are herbivorous, some carnivorous, and when it is considered that the saurians of this epoch peopled at once the seas, the land, and the air, we may reasonably believe that they represented in great measure other classes, and that there is little reason to believe that any great number of other mammals or of birds then existed. The association with them of the marsupial type, which exists so isolated in Australia, is rather confirmatory of this view than otherwise; and the occurrence of coal in the Yorkshire oolites, as well as in the East Indies and elsewhere, is another proof that the general conditions of the earth were still fitted for the rank and luxuriant vegetation of those early epochs, and for the existence of multitudes of huge reptiles, against which Man in his primitive state must have contended in vain. The earth was, in fact, progressing towards a fit state for Man's residence, and the animals which lived at each stage were perfect in their kind, and suited to the conditions of the epoch.

CRETACEOUS.

Succeeding to the extensive fresh-water formation of the Wealden, is a still more extensive, and generally more widely diffused marine formation—the cretaceous. This change is similar to that which will take place if, after the long-continued deposit of fresh-water detritus in the depths of the lakes of North America, the sea shall be admitted by a depression of the surface, and the bottom of the lakes now actually below the sea level shall become a sea bottom. Even a moderate depressiou would cause such an irruption of the sea over a large portion of the country, and marine deposits would immediately commence. If, again, after an accumulation of such deposits, equivalent in thickness to the cretaceous, the whole mass were

uplifted by the action of subterranean forces, the fresh-water deposits might be brought to view by the fracture and removal of part of the marine covering, of which the remaining part would continue as a mural boundary surrounding them, and the result would be analogous to the Wealden and chalk. Commencing at its base, the cretaceous system is sandy, and this division has been named the green-sand formation in England, the quadersandstein formation in Germany,—names derived from the principal peculiarity of the sandstone in each locality. In each it admits of further subdivision into upper and lower, the two being separated in England by a deposit of marl and clay called gault; in Germany by one of marl, marly sandstone and limestone (the plänerkalk). But though these divisions exhibit a striking conformity when viewed at particular localities (if, for example, the green-sand of England be compared with the quadersandstein of Saxony and Bohemia), considerable modifications appear in other localities. In Westphalia and North Germany, a conglomerate and a clay which Cotta considers the equivalent of the Specton clay occur below the lower quader: the pläner is replaced by a blue clay with crystals of gypsum, corresponding still more closely with the English gault; the upper quader is represented by a green-sand, which is surmounted by bright and red marl. The sandstone of the Carpathian Mountains is also referrible to this epoch. On the Continent, the upper limit of the green-sand is not always distinct, as the same lithological character, in sandy marls and sandstones, extends in Westphalia and North Germany high up into the upper section of the cretaceous system; but these are only natural variations, being the necessary result of those local peculiarities which have already been so frequently adverted to. In England, the upper section of the cretaceous formation can be divided into the lower chalk without flints, and the upper chalk with flints, the whole reposing on the chalk marl,—a subdivision which is purely local. In Saxony and Bohemia, the whole section is reduced to beds of flints; in Westphalia and North Germany, the upper member is feebly represented,

but all below it consists of chalk marls and sandstones, far more in character with the green-sand than with the chalk, of which it is proved to be equivalent by fossils. In France, the Maestricht beds resting on the white chalk with flints are at the summit, and from their peculiarities have been considered by some Geologists an upper member, approximating the chalk to the tertiary strata, though their fossils are those of the white chalk, and the chalky character is carried downwards into the green-sand. All these modifications of lithological character must be anticipated by the Geologist, and his skill alone can disperse the obscurity which they occasion as he traces out the boundaries of sea and land, of bay and ocean, at each successive epoch. Sometimes indeed the mineral conditions remain unaltered from one geological epoch to another, as is the case in the Mediterranean, where the Scaglia or white limestone with its flints has been in part deposited during the oolitic, in part during the cretaceous, and probably in part during the tertiary epoch, unless there be a transition member between the chalk and tertiary formations.

Few phenomena are more striking, or have engaged more attention, and excited more speculation, than the occurrence of long lines of flints in chalk; the marked contrast between the dark hue of the flint and the pure white of the English chalk having attracted special attention to chalk flints. The occurrence of silicious nodules similarly arranged is not confined to the chalk, but is observed both in the mountain limestone and in the oolite; nor is the arrangement by nodules always the prevailing one, as in the chalk of Ireland extensive layers or beds are very common, and again in the oolitic and cretaceous portions of the white limestone of the Mediterranean. The origin of flints has excited much speculation, though from the preceding observations it is evident that the question does not refer to the chalk alone. A microscopic examination having shown that they contain numerous infusorial remains, Ehrenberg was disposed to consider that they had been formed almost exclusively of such animals; whilst the dis-

covery of the texture of sponge in flints has led Mr. Bowerbank to ascribe them exclusively to a spongeous origin; and again, others are more inclined to believe that the silica, having been held in solution by thermal waters, was deposited in a gelatinous state and enveloped the sponges and other bodies it contains. It is highly probable that all these causes have contributed to produce the result; and considering the peculiar affinity of silica for organic substances, there can be little doubt that sponges have materially, though not exclusively, contributed to the production of chalk flints. As yet, the comparison of flints and cherts in various formations has not been fully carried out, but it may be assumed that they will exhibit a material and characteristic difference in their zoological remains.

The cretaceous system is peculiarly rich in fossils, the whole mass even of the white chalk, as has been shown by Professor Ehrenberg, swarming with infusoria and other microscopic animals, in addition to the multitude of those of larger dimensions, as echinida, cephalopoda, &c. The spongiadæ and alcyonidæ are abundant: of the crinoidæ there is the peculiar genus marsupites; of the echinida, the genus ananchytes, and a profusion of species of many other genera; of the mollusca generally, the remarkable genera hippurites and radiolides, which with caprina, &c. formed extensive banks or reefs in the cretacean sea, deserve special attention, as their true nature is still doubtful: the genus spondylus (plagiostoma and podopsis) has a very characteristic species in plagiostoma spinosum; the genus pecten affords in P. quadricostatus and P. quinquecostatus the type of a new genus, rhynchonella: the genus inoceramus abounds; whilst of the cephalopodous division there are many most characteristic genera and species, such for example as the genus turrilites, a chambered shell with an external turreted form, the beautiful genus baculites, which unites a straight form with the sinuous septa of the ammonites, the hook-shaped hamites, and a great number of ammonites and nautili, producing in this one order an assemblage so strangely different from that of our

present tropical seas, where the single genus nautilus alone remains, as justly to excite our admiration and surprise. In fish there is a nearer approach to the existing epoch, as the genera squalus, galeus, and lamna occur; of reptiles, there is the peculiar genus mososaurus, as well as the pterodactyl or flying lizard. In the flora the cretaceous approximates more closely to the existing epoch, as fifty-one species of dicotyledonous plants have been discovered in the quadersandstein of Silesia, some of which are nearly allied to the very common genera willow and maple.

Practically, the chalk hills are well known for their smooth outline and surface, and for the short herbage of their downs, so fitted for sheep pasture, whilst the marly beds of the lower portion of the system have long been known for their fertility, as noted by White of Selborne. In countries where the chalk is more indurated, and resembles the oolites, as in Greece, the tame character of its hills is changed to a far more bold and striking outline, resembling that of mountains of quartz rock. Chalk is valuable for lime, being easily worked and burnt, and, though soft, can be used as a building stone; but the white limestone of the Mediterranean, which belongs partly to the chalk, is an excellent building stone, though, being hard and brittle, dangerous in military buildings exposed to cannonade. Flints, made up into a species of concrete, and strengthened by stone quoins, were extensively used in the walls of ancient churches, and are still so applied; they are also used as a road stone, but being extremely brittle, and breaking into fragments with sharp cutting edges, cannot be considered well fitted for such a purpose. Of the lower part of the system, the green-sand or quaders ndstein is more practically useful on the Continent than it is in England, though the soil proceeding from it is much less fertile. In Saxony, the quadersandstein—so called from its breaking into quadrangular portions—is celebrated as a building stone, the colour being pure and good; and as the pläner (or gault) is there mostly deficient, the upper and lower quaders are almost

in contact, and each yields its valuable bed of building stone. In other localities the position of the pläner is marked by a line of water springs which it throws up, and taking an unusual development, it stretches up into and occupies the place of the upper quader, which is there wanting. The boundary hills and the bottom of the valley of the Elbe at Meissen are of granite and syenite; and at Dresden a depth of 856 feet was bored through without arriving at the granite. If this accumulation of quadersandstein and plänerkalk could be removed, and the basin containing it laid bare and then filled with water, the bottom of the inland sea thus formed would be more than 500 feet below the present sea level, and the surface of its waters about 300 feet above; but as the sandstones and limestones were a marine deposit, it appears that after an epoch when in not very distant countries land plants were growing, and an extensive fresh-water deposit forming, this basin must have been depressed more than 300 feet below its present level, and have been a deep hollow in the sea; another of the surprising results, like that of the Wealden, which geological research has made known.

In America the upper chalk is represented by beds of sand and clay totally unlike this portion of our English cretaceous system. The fossils, or in other words the zoology of the beds, is however a sufficient proof of contemporariety in epoch; and here, as in the existing epoch, local mineral variation is found connected with a general fauna. One of the most remarkable zoological facts of this formation is the great development of the ammonidæ, which appears the result of some great law of nature. In the Silurian epoch the nautilidæ appear to have arrived at their stage of highest development, exhibiting every variation of form, as the straight in the orthoceratites, the oblique, the open, &c., and then suddenly diminished, though the type is continued in our present fauna. The ammonidæ, on the contrary, commenced with the muschelkalk of the trias in the genus ceratites, or perhaps with the goniatites of the carboniferous, flourished in the oolites, and finally attained their full

development in every possible variation of form in the cretaceous, where they appear for the last time; the straight ammonites or baculites, the crooked or hamites, the open whorled or crioceratites, the obliquely whorled or toxaceratites, the turrilites, and many others, passing away from the organic world for ever.

This history of the ammonites, when compared with that of the nautilidæ, induces a belief that the type of nautilus must have commenced at still earlier epochs, of which as yet no zoological evidence has been attained.

TERTIARY CLASS OF FORMATIONS.

At this period of geological history, the present order of creation may be said to begin, as the remains of animal species which still exist are blended with the relics of the extinct. Sir C. Lyell has adopted this combination as the groundwork of his classification, and invented terms to signify, as it were, the dawning and gradual progression of the existing creation; his subdivisions depending on the proportional number of existing species in each, a principle of classification which, though beautiful, requires to be applied with much caution.

Co-operating with M. Deshayes, the well-known French conchologist, Sir C. Lyell matured his plan from an examination of about 3000 species of fossil shells, and their comparison with about 5000 living species by M. Deshayes, and exhibited the numbers of recent species in each division, as below:—

Newer Pliocene of Sicily . .	90 to 95	per cent.
Older Pliocene, or Sub-Apennine .	35 to 50	"
Miocene of the Loire and Gironde .	17	"
Eocene of London and Paris .	3½	"

the distribution of the fossils submitted to examination having been,

Pliocene, older and newer	777
Miocene	1021
Eocene	1238
	3036

Sir C. Lyell, in the 3rd edition of his Manual (1851), further

remarks, that since the epoch of comparison, the species both of the fossil and existing faunæ have been greatly increased, the number of recent known species having been raised from 5000 to 10,000.

In studying these formations it must be remembered that the existence of species identical with those now living can alone be explained by a growing approximation to the present physical conditions of the earth; and in consequence that those variations which are now observed in local faunæ must be expected also in those of the tertiary epochs. The existing fauna is in fact composed of a number of local faunæ, of which many of the species are quite peculiar, and as distinct as the species of successive tertiary formations, but which are bound together by other species which have, if not an universal range, a distribution at least as wide as the species of more ancient epochs. And in a similar manner the several tertiary deposits of widely separated regions must be expected to exhibit an assemblage of local species connected together by other species of more extended range. In determining, therefore, the exact place of a deposit in the series of tertiary formations, the fossils should be compared with the recent species of the neighbouring coasts and seas. On this principle, so well explained by Sir C. Lyell, the contemporaneous fossils in deposits of each tertiary epoch, and specially in the more recent, may, at various parts of the earth's surface, have scarcely any resemblance to each other, although in each locality conforming to the general rule of a growing approach to the recent types; and it is therefore sometimes very difficult to determine the exact mutual relation of such local deposits to each other. To the true tertiaries have been subsequently added the post-tertiary, post-pliocene or quaternary strata, in which the organic distinction vanishes, although from their position and other circumstances it is impossible to associate them with strata still in course of deposition; as, for example, beds of clay or sand containing shells identical with those now existing, which occur inland at an elevation probably 200 feet above the level of the sea, and by their posi-

tion in inlets or indentations of more ancient rocks mark out the muddy bottom or the sandy shore of an ocean under very different conditions to the present. Though comparatively recent, the tertiary formations exhibit accumulations of detritic matter which rival in magnitude those of former epochs, as, for example, in the London clay of the eocene epoch which has been found 500 feet thick, in the nummulitic limestones of the Mediterranean which appear a repetition of the cretaceous beds, in the similarly remarkable tertiary limestones of North America, in the immense deposit of molasse or soft sandstone of Switzerland, and even in the vast lacustrine deposits of sands and marls of Auvergne.

The marine and fresh water beds appear to have been deposited in extensive basins, and it is remarkable that the great cities of London and Paris have been founded on such ancient basins, whilst in the brown coal which is spread over a large portion of Germany, and abounds in land plants, though not apparently connected with a basin sufficiently marked by any depression of its surface to explain so great an accumulation of vegetable matter as that at Zittau in Saxony, where it affords the elements of a coal formation. In general, the tertiary deposits of England do not attain any great terrestrial height, no elevating force having been exerted beyond what was necessary to raise them partially above the sea level; but along the axis of greatest movement, both in Europe and America, the case is different, the Nagelflue of Switzerland with its brown coal and limestone, skirting the Alps in a chain of mountains 6000 feet high, the thickness of the deposits being 2000 feet, and the nummulitic limestone occurring in the Swiss Alps at an elevation of 10,000 feet. These deposits are very widely spread, occurring in North and South France, in the South of England, as also, in the upper members, in Scotland and Ireland, in North Germany, and along the Rhine in Middle and South Germany, on both slopes of the Alps and Apennines, in Sicily, on the coast of Africa, and specially on the shores of the Mediterranean, in Poland, in North and South Russia, in North and South Asia,

as, for example, in the Bay of Bengal, in the East of North America, and in Equatorial America, &c.; so that in almost every part of the globe traces have been found of that gradual approximation to the present physical and zoological conditions of the earth's surface which is learnt from the study of tertiary deposits. In a few Northern localities, it is supposed that a tendency towards a colder climate can be traced within the later tertiary epoch; but generally the climate appears to have continued nearly tropical.

EOCENE.

The English tertiary deposits are very local, and only important in the lower members. The basins of London and Hampshire are the lowest geologically, and belong to this period. They are bounded and underlaid by the chalk, and their strata consist of sands, clays, and gravels. Comparison between the French and English tertiaries has shown that the eocene deposits may be subdivided, and that the upper portion is deficient in Great Britain, whilst the middle subdivision includes the fresh-water beds of Hampshire, and the upper sand or Bagshot sand, and the lower the London clay, and the plastic clay which consists of alternating beds of clay, sand, and shingle, peculiarities which, though local and not accompanied by any important zoological differences, are within these districts of great practical use, as will be seen in treating of the subject of 'Springs.' There are several shells, such as nautili, &c., of a tropical type, and many plants also, more than seven hundred of which have been discriminated; and again in the reptiles, the teeth and bones of many crocodiles and turtles, and even the bones of a large serpent, have been found. The remains of a bird, of various quadrupeds, and of a monkey of the genus macacus, bear also testimony to a warm climate.

The deposits of the Paris basin are very different in mineral character from those of the London basin, though connected with them by zoological evidence. The London and Bognor clay beds, which are so remarkable in the London basin,

have been associated by Mr. Prestwich with marine shelly beds of the lower portion of the Paris basin, and the English plastic clay and sands with the sands, plastic clay, and lignite, of the base of the French system; whilst the Bagshot and Brachlesham sands, the Boston beds, and the fresh-water and fluvio-marine beds of the Isle of Wight, Hordwell, &c. correspond to the silicious and fresh-water limestone, the marine calcaire grossier, the marine sands and sandstones, and the fresh-water limestone, marl, and gypsum of the middle portion of the Paris basin; the Fontainbleau sandstone and the upper fresh-water limestone, marl, and silicious millstone having, as it is supposed, no equivalents in the London basin. The celebrated Montmartre gypsum quarries were the classic ground of the great Cuvier's wonderful researches and discoveries. The range of the London clay has been extended through a large portion of the N.E. of Europe, by Dr. Girard, of Berlin. In other countries the variation of mineral character is even more striking, indicating a still greater variation of the conditions of deposit. In the Mediterranean Islands the white limestone ranges without any marked physical difference from the oolite epoch up to the lower tertiary inclusive, and in the United States the eocene beds are in part represented by soft chalky limestones, exhibiting even the external physical characters of our chalk downs. A gigantic cetacean, called by Owen zeuglodon, occurs in the upper beds, and multitudes of orbitoides, a fossil resembling nummulites in form, in the lower.

The great mineral difference in these deposits in the two basins leads to similar differences of practical application. The London clay beds sometimes abound in calcareous nodules, used for making Roman cement, which often contain marine shells, the remains of turtles and fruits; and when traversed by cracks and veins dividing the mass into parts, as by septa, are called septaria. Harwich and the Isle of Sheppy are well-known localities of these nodules. In the Paris basin, the calcaire grossier furnishes, in some of its varieties, very good

building stone, and the silicious fresh-water deposit yields an excellent millstone.

MIOCENE.

The miocene epoch is represented in England by the lower portion of the Suffolk crag, which is subdivided into the coralline crag below and the red crag above. The coralline crag is very local, and is generally calcareous and marly, being a mass of shells and small corals, whilst the red crag is a highly ferruginous grit. Although the thickness of both members of this deposit is very small, not together exceeding 60 or 70 feet, the number of fossils is very great. Mr. Searles Wood has obtained 230 species of shells from the red crag, and 345 from the coralline, 150 of which were common to both. There is a considerable difference in the proportion of recent shells in the two divisions; and as the lower had been disturbed before the deposition of the upper, they exhibit a striking modification consequent on the change from a coral reef to a shingle bottom, an example which shows that coral reefs are not necessarily of great thickness, the product of almost infinite ages, or that they rest on the peaks of submarine volcanoes; since now, as in the ancient epochs, a growth of coral may have commenced on a sand or mud bank, have been interrupted by a new deposit of a similar kind, and then again renewed, such alternations being frequently observable in the carboniferous period. The faluns of Touraine, the Bordeaux beds, the sands, marls, and conglomerate of Piedmont, and part, at least, of the molasse of Switzerland, belong to this epoch.

Practically, the formation varies in importance in different districts. In Suffolk, the coralline crag yields a soft building stone, and the marls are useful as manure. In the Styrian Alps, limestones of a coralline and of an oolitic structure are largely developed, and the molasse, from the ease with which it is cut, is also valuable.

PLIOCENE FORMATIONS.

The lower pliocene includes in England the celebrated red

crag of Suffolk, so remarkable for a great quantity of coprolites and highly phosphatized bones. Much difference of opinion still exists as to the true age of this deposit, which, from its physical character, must be considered an ancient drift of beds. Although many eocene fossils occur, the association with them of recent forms makes it difficult to conceive that this is not comparatively a recent formation. The red crag of Norfolk belongs to the newer pliocene, being more recent than that of Suffolk, and it is unnecessary to dwell longer on the upper or newer pliocene formations, which are very feebly represented in the British Islands, being confined to minor deposits of sand, gravel, and clay. On the Continent, however, they are very largely developed, extending in Sicily over nearly half the island, and attaining an elevation of 3000 feet, being composed partly of calcareous and partly of argillaceous strata, and exhibiting by the occurrence of recent species of shells amidst such a mass of stratified matter, a striking proof of the accuracy of geological reasoning as regards the older formations. In Italy, the Sub-Apennines range from the miocene up to the newest pliocene, affording a striking exemplification of the great development of these comparatively recent strata, and the blue clay of the Mediterranean, rising sometimes to the height of 1000 feet above the sea, is also of this epoch. The thickness of the Norwich crag, consisting of sand and loam, and considered an estuary deposit, is small, about 40 feet, and the Suffolk crag belonging to the older pliocene is also insignificant in its vertical extension. In Sicily, the newer pliocene is a vast marine deposit, but in Russia there is an equal extension of fresh-water deposits, a vast mass of argillaceous limestone around the Caspian, which Sir R. Murchison calls the Aralo-Caspian, or Steppe limestone, containing univalve shells of fresh-water origin associated with bivalves, which are common to partially saline or brackish water, but without corals. The thickness of this supposed member of the pliocene is in some places between 200 and 300 feet, and it attains elevations of 700 feet above the present level of the Caspian. In like man-

ner the tertiary strata of Vienna correspond to the London clay at the base, but merging at the top into the pliocene includes a fresh-water deposit of limestone; these beds passing into the more northern or Russian deposits. It is remarkable that whilst the species of testacea of the newer pliocene formation were nearly identical with those of the existing period, there should still have been so marked a distinction in the animals of a higher class, as is proved by the bones of the various celebrated bone caves and ossiferous breccias of all parts of the globe, a difference which continued even beyond the limits of the pliocene. It is also remarkable, that whilst in the Old World (though animals of a high order now confined to warm climates extended far northward of their present limits) the general type of extinct organisms conforms to that of animals still existing, the type in Australia now peculiar to itself, though European in the oolitic period, assumed its distinctiveness in the tertiary period, that vast region having even then been isolated from the rest of the world.

The connection of the ancient lava currents of Auvergne with the tertiary strata requires a few additional remarks. The age of the stratified deposits of the country is considered by Sir C. Lyell to be generally eocene, although some portions may possibly extend upwards to the miocene, whilst the base of the system is granite, and therefore either eruptive or metamorphic of a more ancient date. Sir C. Lyell describes successive gravel beds, the alluvions of different ages, covered by lavas, and points out that the lava current of the Puy de Tartaret has passed over a red sandy clay, rich in the bones of mammals, which are associated with those of reptiles and of birds, and with several *recent* land shells. The bones, though closely allied to those of recent species, are considered distinct, and include the fossil horse of Owen. Sir C. Lyell, from the superposition of the lava, is enabled to affirm that the bone beds, in whatever way the animals were destroyed and their relics so imbedded, belonged to the alluvial formations of the river bed and river plain at the time of the flowing of the lava

of Tartaret; whilst he shows from an ancient Roman bridge, not more recent though probably older than the fifth century, which spans with its two arches the river Couze and abuts on both banks against the lava which had thus been cut through and formed into the present existing ravine fourteen centuries ago, that the lava of the Puy de Tartaret was, as respects the events of human history, of great antiquity, and referrible either to the close of the newer pliocene or to the post-pliocene period, a period when "the mollusca were identical with those now living, although a great many of the mammalia belonged to species now extinct." This recurrence of alluvions and even of ossiferous beds, with overlying streams of lava, deserves especial attention, as it is utterly impossible to reconcile such repeated volcanic eruptions to any one catastrophe.

The beds of sand and gravel spread over so large a portion of the earth have always attracted attention, and for a long time were ascribed to the passage of diluvial waters over its surface; but a rigid examination of the peculiar characters of these deposits has shown that such an opinion is untenable: for example, they sometimes consist of deep beds of sand, separated by fine clay partings into a multitude of beds; sometimes they are composed of alternating layers of sand and gravel, which exhibit cross lamination; sometimes they consist of clay with imbedded boulders of various rocks and of various sizes, the term boulder being properly applied to rolled or rounded masses; sometimes they contain marine shells, sometimes bones, and sometimes they extend over large spaces and occur at great altitudes and of great thickness, without any trace of organic bodies. Many marls and clays or silt, with land and fresh-water shells, belong to this division. When the various circumstances attending such deposits are considered, it is evident that they cannot be ascribed either to one great wave or to the rush of tumultuous waters, continued only through a very limited time. The substances of which these deposits consist having been broken up, triturated, and moved by water, the term drift has been applied to them; but though all these sub-

stances have been more or less drifted, their distribution has been modified by many local peculiarities, giving rise to deep deposits of sand in one place, and to long continuous banks or shoals in others, just as in recent drift the sounding lead testifies that such modifications are now taking place. The great 'erratics,' or those large angular masses of rock which often rest on the surface of sand or gravel, are rightly separated from the beds on which they lie and distinguished from the rounded boulders connected with these beds, or with the clay which has accumulated in hollows of the earth's surface: they are now generally believed to have been transported by ice, as fragments of rock are now drifted along on icebergs. In Northern Sweden the phenomenon of drift is strikingly exhibited in long traînées, whilst the rocks are worn down in undulating surfaces, and sometimes exhibit rounded northern and abrupt southern sides, corresponding to the wearing action of such loose materials in progressive motion.

Without entering into details, it may be generally remarked, that the superficial detritus, so long called diluvium, exhibits itself in several distinctive phases. 1. As deep beds of sand, not heaped up in one mass, but manifestly deposited in successive layers, and which though doubtless triturated by the action of water, and even moved along by currents, are comparatively tranquil and regular deposits. 2. As lines of gravel and of gravelly clay, with rounded boulders which sometimes surmount the more quiet deposits, and by their definite direction in such traînées for even hundreds of miles, indicate the action of currents moving in Northern Europe, in a slightly divergent direction from the Scandinavian Mountains to the south on the one hand, and from the south to the north on the other; indicating that the transport was not effected simply by the usual submarine currents flowing from north to south, but partly, at least, by undulations of the bottom, which caused powerful waves of translation in all directions from the axis of disturbance. 3. As 'erratics,' or large angular blocks, which are not immersed in beds of sand, mud, or gravel, but rest

on their surface, or on ridges of rock where there is no superficial covering; and it has been hitherto considered that moving ice is the only sufficiently satisfactory cause of the translation of such masses, which, having preserved their angles, cannot have been exposed to the rolling action of water. 4. In the preceding cases, the detritus is supposed to have travelled from a distance; but it is very often partly local, and then is produced by the wear of the adjacent rocks, either by the direct action of the sea against them, or by the attrition of fragments when moved by the tidal wave along a coast or a bank. Where both forms of detritus occur, it is difficult to discriminate between them, or to determine which is the underlying or overlying bed. 5. The connection of the boulder formation, and the phenomena of erratics with ice as a motive agent, seems further supported by the fact that both in the old and new worlds they are observed only in regions where the effects of extreme cold might be looked for, the boulder formation having in Europe been traced southward to the 52° of latitude, and in America to the 38½°, where it is occasionally more than 200 feet thick and bears on its surface 'erratics,' rivalling in size those of Europe, a block of greenstone 100 feet in circumference having been noticed by Sir C. Lyell, whilst the largest European erratic on the Island Fohnen measures 44 feet across; and further, that having ceased within the tropics, such appearances are again observed on approaching the antarctic zone. The surfaces of rocks, when laid bare, are in America as in Europe striated, furrowed, or smoothed; and as these phenomena extend from the northern elevated districts towards the south, they required a general force, such as that which now effects the transmission of the Polar waters to the Equator, and cannot be explained by the waves of pulsation consequent on elevating forces alone; for though to the north of the Scandinavian chain the 'erratics' have moved to the northward, their extension in that direction has possibly not been traced sufficiently far to remove them from the possible action of glaciers, which it is reasonable to

assume must have co-existed with the floating sheet and berg of ice, and co-operated with them and with marine and lake currents in transporting fragments of rocks by land and sea.

6. On examining the scratches and grooves on rocks it seems scarcely possible to doubt that many of them have been produced by pebbles moving with and immersed in the bed of boulder clay which once covered the rocks. Various causes have been assigned for this movement, such for example as land-slips, the saturation of masses of detritus and their descent as semi-fluid mud down the slopes of mountains and along valleys, and lately coast-slips of matter below the tidal line, a cause suggested by Mr. R. Mallett, who considers it sufficient to account even for the movement of erratics; but whilst to each of these causes some peculiar local effects may be ascribed, neither can be considered sufficient to account for the more general phenomena. The mud, sand, and gravel along the coast is doubtless often put into motion, sometimes by the tidal wave producing wear, polishing and grooving in lines parallel to the shore, and sometimes in consequence of the sudden removal of its support in deep water by the excavation of its bed by currents when the shore detritus sinks in and moves perpendicularly outwards; but in these cases the moving matter is in a semifluid state, and can neither be expected to carry on its surface large bodies, nor hold fast in its grasp the angular fragments which scratch and groove. The only condition in which such effects may be ascribed to the movement of a solid bed of clay and its imbedded angular fragments, is when the mass is retained in a compressed and firm state by superincumbent pressure; and there can be little doubt that the accumulations of mud and other detritus which have been formed in the deep recesses of the ocean, and so consolidated by pressure as to support the heaviest fragments, are often broken up by the convulsive elevation of the sea bottom, and by a change of its level are put into motion and gradually slide along the inclined plane thus formed, carrying forcibly with them the sharp pebbles which groove and scratch the rocks below. And further, it

should be remembered that when the surface of a rock, laid bare by the removal of clay or other matter, is examined, the results of several successive actions may be manifest, as, for example, the rocks may have been polished by the attrition of sand carried along by ordinary currents, and subsequently scratched and grooved by the movement of consolidated masses of clay and the sharp stones imbedded in them.

In countries where the tertiary strata are fully developed, either as deep sea or as great lacustrine deposits, they supply valuable building materials both in limestone and in sandstone. The fossil bitumen so extensively used in asphalte pavements, namely, that of Bastenue, a small village of the South of France, 15 miles north of Orthez, is tertiary. The formation in which the bitumen is found rests on a sandy limestone, which has been allocated to the cretaceous system, and it consists of beds of variously coloured sands and clays, which are 50 or 60 feet deep, and covered by gravel and sand, which extend many miles in every direction. These beds are usually horizontal, though sometimes much disturbed by the intrusion of igneous rocks. Under about 45 feet of variegated sands and clays there is a small quantity of bitumen in a bed of blackish sand 4 feet thick: from 5 to 15 feet of bitumen are then observed, the upper part of which is mixed with loose and coarse sand, the lower being more compact, and mixed with finer sand. In some places there are 10 to 15 feet of sand without bitumen, whilst in others the bituminous sand is thicker, and rests directly on the secondary sandy limestone. In two localities marine shells have been found in the bituminous sand, and referred by Mr. Pratt to the miocene period. The shells are arranged in layers, and are quite perfect, the valves not being separated from each other; and the bitumen, when in a soft or liquid state, was, in Mr. Pratt's opinion, forced into the shells, after their deposition in the sands in which the animals lived, filling even their smallest cavities. The eruption of the bitumen is supposed to have been connected with the appearance of ophite, an igneous rock which has produced such great changes

in the Pyrenees. The bitumen is easily cut when first exposed, but in a few days it hardens so much as to become incapable of purification: the purification is effected by boiling the sandy mixture in a large quantity of water two or three times, when, by continued and careful stirring, the sand gradually settles to the bottom, while the pure bitumen rises to the surface and is taken off. A small portion of bitumen occurs in the tertiary rocks of Anti-Paxo, and again in a larger quantity at Zante. The existence of gypsum and salt in the tertiary strata has been already noticed.

Before quitting the remarkable geological epoch embraced by the tertiaries, it is desirable again to bring before the mind the zoological history it has unfolded. Approximated as it is to the existing world by many still existing species, there are sufficient peculiarities to stamp upon it individuality, whether the lower or the higher portion of the organic creation be made the basis of comparison. The tertiary world is as distinguished from the existing by its corals as it is by its mammals; and whilst it rejects any decided union with either the past or the present, it manifests numerous affinities to both. In the mollusca, the nautiloid type which flourished in its most extended development of form in the Silurian epoch, was still represented by two genera,—aturia (clymene) and nautilus, and seven species. In the reptilia which swarmed in the oolitic epoch, and appeared so early as the Devonian, the tertiaries were rich, the London clay alone having furnished in the three families of marine, fluviatile, and marsh turtles, relics of no less than 27 species, and in the marine genus chelone 11 species, whilst in the whole extent of our present world only five species have as yet been discovered;—in the crocodilia, three crocodiles, one alligator, and one gavial, some of which exhibit that mixture of types which has been noticed in reference to the combination of the lizard and batrachian types, in the early reptiles of the old red and carboniferous epochs; in the lacertilia, one true lizard; and in serpents, six species, some of which were gigantic and probably marine. In mammalia,

the more recent deposits, including bone caves, exhibit some species which are yet existing, such as the red deer, the reindeer, the goat, the wolf, and the fox; others closely allied to the existing species of ox, horse, hyæna, rhinoceros, hippopotamus, and elephant, associated with extinct forms; and here, as in preceding cases, particular orders seem to have attained a peculiar development, namely, the edentata or toothless and the pachydermata or thick-skinned animals, including the gigantic fossil sloth or mylodon robustum, the mighty dinotherium equalling the elephant in size and with tusks turned downwards as if to tear up the ground, the hyracotherium, anthracotherium, the lophiodon and palæotherium, resembling the American tapirs, the anaplotherium, which seems to connect together the genera rhinoceros, horse, hippopotamus, hog, and camel,—and many other extinct genera, besides the cetaceous genus zeuglodon, which may be considered the marine representative of this type. But amidst all these strange forms, including the glyptodon or giant armadillo, there appear representatives of that order, the quadrumana, which at least suggests, even if it caricatures, the form and actions of man, in extinct species of apes, and even of the ourang. The bat also had begun to flit about in the dim twilight of a world which as yet had not been tenanted by Man; and on every side it appeared that the Creator had nearly established that balance in the numbers, powers, and functions of other animals which would render the world fit for the reception of the greatest work of creative power—a being endowed with reason, or with the power of investigating and studying his own structure, and comprehending the relations which connect him at once with the great Creator, and with all the works of creative power.

QUATERNARY, POST-TERTIARY, OR POST-PLIOCENE—RECENT.

Our inquiry has now come to that point where, though we still see in the recent results of geological phenomena evidence

of the formative processes of nature,—coral reefs still rising from the depths of the Pacific,—conglomerates being still formed in the Mediterranean,—beds of marl being still deposited in lakes,—travertin being deposited from mineral springs, —and peat being observed to have formed over fresh-water shells, the bones of land animals, and even the works of human art,—we are still kept at a distance from the recent epoch; for although organic relics are all of recent species, they are generally arranged in positions and associated with detritic matter of such a description that their appearance indicates the action of forces prior to the present order of things. These masses, the true post-pliocene, though now exposed to view and frequently found at high elevations and of great depth, have evidently been, like the antecedent formations, under the level of the waters either of lakes or of seas, whilst true recent strata are, in most cases, still in the position from which the former have emerged. To this obscure region must be ascribed raised beaches or those remarkable accumulations of gravel which though far above the present level seem to mark the former position of the sea boundary or shore, or which bordering the sides of lakes show in like manner a depression of the surface of their waters. Raised beaches, as well as the pleistocene deposits, have been ably examined by Mr. Smith, of Jordan Hill, who has noticed 150 species of shells in those of European origin; but it must be manifest that at this point, where the ancient strata are blended with the recent, ancient beaches whether marine or lacustrine must be studied in direct reference to adjacent localities, as the changes of position or altitude do not imply an alteration in zoological conditions.

Recent or Alluvial.—The natural phenomena which can be now studied are valuable guides in estimating those of past epochs; and by many analogies of alluvial deposits may be learnt the mode in which more ancient deposits have been formed. The action of rivers may be estimated by the extension of the deltas at their mouths, and that of the sea observed in all its phases. The processes of destruction and of formation

connected with these actions extend over the whole earth, though, being necessarily modified by many local peculiarities, they produce parallel, not identical formations, the contemporaneity of which it will be difficult at more remote ages to determine. These formations may be divided into mechanical, chemical, and organic, and also into land and sea formations, volcanic products being connected with each.

Mechanical Deposits.—Torrents and rivers, in their course through mountain regions, carry along with them a mixture of large and small fragments torn from the boundary rocks, and deposit their load in the lower and more tranquil portion of their course, as gravel, sand, or mud,—the nature of the deposit and the distance to which it is carried being proportioned to the strength of the current; and this simple and constantly occurring natural event exemplifies the removal of portions of rocks from their native bed and their subsequent deposition, and the formation of alternating beds of clay, sand, and gravel. When a river passes through rocks rich in ores or in precious stones, its waters often separate from their matrix those substances which from their superior weight remain behind, whilst the finer matter is hurried onwards. Deposits of this kind are valuable from the quantity of ore and of gems which they sometimes contain, and which are separated by repeating the natural process or washing away the remaining fine matter. Particles of gold, platinum, iridium, rhodium, palladium, osmium, chrome, and magnetic iron, are obtained in Wicklow, in the Ural chain of Russia, in Brazil, in California, Australia, and elsewhere; the term stream gold or stream tin, &c. being applied to such products. As yet, platinum has only been obtained in this secondary manner, and the greater proportion of gold is similarly procured, as well as a considerable part of the tin, as also the zircon of Bohemia, the chrysoberyls and hyacinths of Ceylon, the diamonds of Brazil and of the East Indies. In Borneo, gold has been found mixed with alluvial matter in limestone caves. The gravel of the Rhine is estimated by M. D'Aubrée to contain an

amount of gold equivalent in value to 165,828,000 francs, or £6,564,025.

Deltas.—Where rivers discharge their suspended mud into the sea, and where the coast is shelving, and there is no powerful marine current, a delta is often formed by the deposition of mud at the point where the waters have lost their transporting power. It usually commences at the centre of the river's mouth, an island being first formed, which goes on extending and widening till a triangular space is occupied by the deposit, the apex being directed upwards, and the base facing the sea; and this form having been first noticed in the mouth of the Nile, the name Delta was applied to it from the Greek letter of that name. Sometimes, as in the Nile and the Rhine, several islands are simultaneously formed, so that the delta is finally a compound one, and is separated by various channels. The delta of the Ganges is still more remarkable than those of the Nile and Rhine, its perpendicular depth from the apex to the base being about 180 miles, and therefore exhibiting a formation comparable in extent to many of those of past geological epochs.

From the action of the Sea.—The sea effects a change in the form and position of the land with which it is in contact; for whilst at one point its waters encroach upon and carry away the land, at another they deposit new matter, and increase it; and as they contain from three to four per cent. of various mineral salts (as chloride of sodium, chloride of magnesium, sulphate and carbonate of magnesia, sulphate and carbonate of lime), the formations produced are often more fixed and solid than those of fresh water. This is specially the case in warm climates; and as the fragments of shells as well as comminuted portions of calcareous rocks are often mixed with the deposits, sandstones are sometimes formed, sometimes limestones, sometimes conglomerates. In a formation of this kind at the Island Grande Terre, near Guadaloupe, human remains have been imbedded, and many such are in progress of deposition below the waters of the sea, and will be brought to

light by such upheavals of the coast and sea bottom as that which so strikingly affected the coast of Chili.

Chemical Deposits.

Calc Tuff and Calc Sinter, or Travertin.—All spring waters are charged with mineral matter, which, coming to the surface, they, in their course, deposit by the influence of light, air, evaporation, loss of temperature, absorption, and escape of carbonic acid. Cold springs charged with lime yield in this manner calc tuff, or sinter in the form of calc spar, and hot springs in that of arragonite. Calc tuff is usually a porous mass, but sometimes its layers are sufficiently firm to be used in building, and are then valuable from their lightness. The most remarkable example of such 'travertin' formations is to be found in Italy, and so rapid is the progress of deposition, that at the Baths of San Filippo, a mass, 30 feet thick, has been formed in twenty years. These springs are made use of to procure stone casts, the lime being deposited in a firm and solid state on models immersed in the water.

Silicious Tuff, or Sinter.—Thermal springs deposit much silex on cooling. The hot springs of Iceland, and especially the Geyser, are of this description. At intervals of a few minutes, a lofty column of hot water is thrown up, and then a dense fog overspreads the surrounding ground, and from this condensed spray the silex is deposited in the porous form of tuff, or sinter, whilst, in the interior of the basin, a species of opal is formed. In the Azores several springs deposit silex; and it is very probable that semi-opal and hyalite, which are frequently found in the crevices of basalt, and, in short, most of the silicious minerals which are so abundant and so beautiful in that rock, have been formed in a similar manner by the filtration or absorption of the water by which the mineral matter had been originally dissolved.

Bog Iron (Limonite).—Ferruginous springs or waters deposit a brownish red scum of peroxide of iron on their banks, or at the bottom of bogs and marshes masses of iron ore,

which has been called from such localities bog or marsh iron; and as sand or gravel may be mixed up with and consolidated by the mineral matter, a variety of ironstone is formed, which has been called sand ore. In Sweden, bog ironstone has been fished up from under the sea, where, according to Hausmann, it is still produced, and it would be interesting to compare the microscopic structure of this ore with that of fresh water. The presence of phosphoric acid in bog iron ore, so unfavourable for smelting, is probably due to the decay of organic bodies in the water during its formation.

Deposition of Saline Bodies.—The saline deposits thrown down by springs, streams, and lakes are not extensive. From the mineral springs of the Baths at Vienna is precipitated a fine powder, consisting of gypsum and muriate of lime. In the South of Russia, several lakes annually overflow their banks and deposit a saline crust; a phenomenon which is much more common in the lakes and in the very low grounds of the warmer zones. In Egypt, soda has in this manner been deposited in large quantity. The extensive turf moors at Franzensbad, near Eger, are partly coated with a white saline crust of sulphate of soda (Glauber salt) and sulphate of iron. Some salts exude out of rocks, as saltpetre (nitrate of potash or nitre), in the limestone caverns of Brazil and of Ceylon.

Mineral Oil, or Pitch.—In several parts of the earth there are springs of a mineral oil which on drying becomes either asphalte or a species of coaly mass. The Carpathians and the vicinity of the Dead Sea are rich in these springs, and in the island of Trinidad they almost form a sea of asphalte.

Organic Formations.

Turf.—This vegetable formation is sometimes covered by more modern mineral deposits of little extent, and sometimes exhibits a passage into brown coal. Turf consists principally of an accumulation of marsh and water plants, especially of various species of moss, the lower layers of which have in succession died, and through the action of humic acid been

changed into a peculiar brown, felted, slimy, and combustible mass. In some layers of turf, the remains of plants are so decayed and changed that their original condition can only be inferred, but in others the actual species of the moss can yet be determined. In some bogs, the growth appears to have ceased, whilst in others vegetation is still vigorous on the upper surface. In Alt-Warmbrücher moor, near Hanover, cutting for the second time, the turf has been re-formed, according to Leonhard, in fifty years, a layer from 4 feet to 6 feet thick having been in course of formation during the last thirty years. At Franzensbad, near Eger, a similar fact has been observed, the exhausted turf hollows having been again filled with new turf plants in from ten to twenty years, which are formed into useful turf in from fifty to one hundred years. The great bogs of Ireland are amongst the finest examples of this kind of formation, both as regards their extent and depth; and although no very detailed or satisfactory observations have been made on the new growth of bog in old exhausted hollows, where drainage and cultivation have not so modified the conditions as to stop it, a very slight observation is sufficient to show that the first step of the accumulation of moss plants can yet be traced. Keferstein has remarked that turf formations are rare on calcareous and frequent on silicious bottoms, but Ireland is at least an exception to this rule, as turf is abundant in some of the limestone districts, and has in several cases grown over lacustrine deposits of shell-marl. Thick beds of turf occur on the summits of some high hills in Ireland and other countries, where a clay bottom retains the moisture. On the banks of the North Sea, a species of turf is formed from accumulations of sea weed. Large masses of bog have sometimes been detached, and become floating islands, one of which, on the Gördauer lake, in Prussia, was so large as to support a hundred head of cattle, until, in 1707, it was broken into three parts by a severe storm. Sometimes turf is found below the high-water level of the sea, as at Greifswalde and Geageland, on the East Sea, and on the north

coast of Ireland, near Portrush, where the elytra of beetles (still fresh and bright) occur between layers of turf. Turf is also formed in the warm zones, as at San Paulo in the Brazils. In the Irish bogs, the roots, trunks, and fragments of the branches of large trees, both oak and fir, are abundant, and, in several instances, two or three successive sets of the roots stand upright one above the other. Turf affords a connecting link between the existing epoch and the next preceding it. It is sometimes very compact and full of iron pyrites which frequently induces spontaneous combustion and the formation of sulphates, often contains fresh-water shells and is covered by layers of sand and clay, and as it passes into brown coal is more nearly connected with the diluvial than the alluvial section of the post-tertiaries. A bed of turf with stems of trees has been found under a covering of 12 feet of sand, and 7 feet of earth; and at Wittgendorf also, near Sprottau, in Silesia, turf rests on fresh-water marl, and is covered with sand and gravel. A wooden bridge, made by Germanicus in his German war, was found under a bog; and in Galway, a hut and paved passage was found under 30 feet of bog by the late Capt. Wm. Mudge, R.N., both being interesting examples of the manner in which such formations, when unrestrained by cultivation, spread over and deform the surface of the earth. The growth of sphagnum or bog moss being most rapid in the centre of a hollow, where the moisture is greatest, bogs are generally much swollen in the middle, and go on increasing in height and thickness until the slope is sufficient to discharge the waters and limit the growth. Examples are cited where towns once visible from each other, are now shut out from view by the elevation of a turf moss between them.

Submarine Forests.—On various parts of the coast of Great Britain and of the North of France the remains of ancient growths of trees and plants are found in positions below the level of the sea, though belonging to species still living. They are sometimes exposed by the encroachment of the sea on the

coast, and at other times simply by the ebb of the tide, and probably owe their present position to a partial depression of the land: General Lewis has noted a fine example of such forests on the western coasts of Jersey.

Coral Reefs and Islands.—They prevail in the Pacific and Indian Oceans and in the Red and Mediterranean Seas. Recent researches, especially those of Quoy, Gaimard, and Ehrenberg, have shown that the growth of coral does not continue in great depths, and that coral reefs or islands are generally not more than 20 feet or 30 feet thick, and are only incrustations on the inequalities of the sea bottom, whether formed on mountain masses not yet elevated to view, or on banks of detritic matter. Whilst, then, such formations explain the nature of the true coral reefs of ancient epochs, and account for the deposits of shale with calcareous layers of corals so common in the carboniferous system, the formation of the greater masses of limestone cannot be ascribed to the action of coral-polypes alone.

Infusoria.—Some masses of rock consist of little else than infusorial remains, as tripoli, polishing slate, &c. Sometimes the infusoria which have formed these strata belong to extinct and sometimes to still living species, so that the microscope, guided by Ehrenberg, confirms the reasoning on successive creations which had been founded on the contemplation of higher organisms. The silicious skeletons of these minute beings are accumulated at the bottoms of marshes and stagnant waters, as in the turf moor near Eger, and thick beds of a white silicious powder are thus formed, consisting of the unmixed silicious portions of still existing infusoria. Some of these infusorial substances, such as tripoli, polishing slate, &c., have been classed with metals, from their general appearance, but their true character has now been revealed by the microscope. Most infusorial deposits probably belong to antecedent epochs, but that of Eger is evidently recent, and in all countries where waters flow over much decomposing silicious rock infusorial formations may be expected.

Land-slips are also phenomena of the recent, although without doubt they have occurred also at ancient epochs. Whereever a soft stratum is liable to be removed by the action of percolating water, slips in the harder superjacent rock are common, as in the Isle of Wight, &c. They are finely exhibited in Ireland, where the soft liasic and oolitic beds being removed or squeczed out from below the basaltic cap which covers the cretaceous and subjacent strata, the top cracks and slides down, as in fig. 18, which is a portion of the basaltic escarpment of the North of Ireland.

Fig. 18.

CHAPTER VII.

Theory of Springs.

As water is the most important substance in nature, being the solvent by which nutrition is conveyed both to the plant and to the animal, as well as the chief agent by which the mineral kingdom has been again and again both abraded and restored, it is desirable to consider that constant change and movement by which its purity and fitness for performing its several functions are insured. The ocean is the great recipient of the larger portion of rivers and streams which flow over the earth's surface, and its waters are in constant motion, the warm currents proceeding from the Equator to the Pole, and the cold from the Pole to the Equator; whilst evaporation causes a perpetual movement of vapour upwards, which, being condensed, falls in rain upon the earth, and again returns to the sea. These simple processes bring within the reach of organic action a constant supply of this vital fluid in a pure and efficient condition, as springs, rivers, or lakes. The useful distribution of water is promoted by the physical inequalities of the earth; for had its surface been uniformly level, the falling rain would have soaked and saturated the upper strata so as to produce a swampy condition, not probably very dissimilar to that it actually possessed, over large tracts, in the earlier geological epochs. The conjoint actions of elevating and denuding forces have, on the contrary, produced chains of mountains, valleys, basins, and all the minor modifications of these three great forms. In the vicinity of mountains, the effect of this arrangement is readily observed in the river which one day struggles with its riband-like stream through

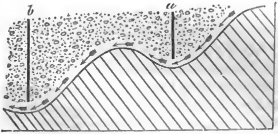
a wide bed of stones and gravel, and the next rushes forward an overflowing and turbulent stream, having been swollen by sudden rains which, falling within the area of its connected valleys, had been collected into one great liquid mass within its bed. The more numerous the feeders and the more closely connected with mountain masses, on the summits of which a very large portion of moisture is always deposited over a comparatively small space, the more sudden will be the rise of the discharging or recipient river. A large portion of water is thus carried off directly by running over the surface, but another large portion percolates through the surface to a greater or less depth, in proportion to its porosity. In clayey soils, this passage of the water is very slow, the surface in wet weather becoming moist and clammy, whilst in dry, it forms a crust fissured by cracks. In sandy or gravelly soils, the passage is very quick, and the surface remains comparatively dry; but where the soil is not very deep, and part of the water is retained by a more retentive substratum, the moisture is readily restored by a continued evaporation and an injurious aridity is prevented, this condition of the surface being more generally favourable for vegetation than an impervious soil. Where, on the contrary, the sand or gravel is very deep, and rests on an inclined surface, it acts as a filter, and a general aridity of surface is produced by the rapid removal of the water. These considerations naturally lead to the following theory of Springs.

1. Whilst part of the rain which falls on the surface runs off as on an inclined plane, another part filters through it, and when collected together in any cavity of a less pervious substratum, forms a reservoir of water. Even on the sides of mountains, especially in damp climates, this process may be observed, for, whilst the general surface becomes wet and boggy, wherever an inequality has led to an accumulation of water, numerous springs are seen issuing as scarcely perceptible rills, which gradually increase as they join with others, and finally emerge in the greater valley as con-

siderable streams. Such is the most simple and ordinary form of springs, from which may be derived every other, by taking into consideration the peculiar modification in each case of the earth's surface; and springs are therefore superficial, small, numerous, and very temporary, where the previous stratum is very shallow, and the inequalities of the substratum slight.

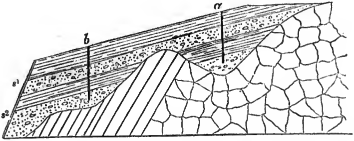
2. In addition to the water which forms the superficial springs on the mountain side, a portion may pass between the underlying rock and the superficial matter above it, whether the latter be a stratified deposit or ordinary detritus resulting from the simple decomposition of the rock itself; or should the overlying deposit be moderately porous, some of the water may pass directly through it to the underlying rock, where reservoirs of water will be formed in its hollows or depressions. This is a case which occurs even in granitic and highly metamorphic rocks; and as open fissures are rare in granite, whilst superficial disintegration, especially in hot countries, has proceeded to a great extent, it affords almost the only chance of meeting with deep-seated springs. Colonel Baddely, R. E., has shown its application and explained the principles which regulate the appearance of springs in Ceylon. The underlying rock is a highly metamorphic hornblendic or syenitic gneiss, the outcropping edges of which having undergone much original modification, are supposed to form an undulated surface—thus, in fig. 19,

Fig. 19.



the hollows being filled up by a detritus, proceeding, according to Colonel Baddely, from the simple disintegration in situ of the more felspathic surface. From the mere inspection of the figure, it is evident that whatever may be the origin of the matter filling up the inequalities of the underlying rock, the water, either in part percolating through it, or passing between it and the surface of the sound rock, must accumulate in the hollows, and that in consequence it would be necessary to sink at *b* to 80 feet for water, although at *a* it had been found at 40; and further, that should the rock under *b* slope gradually off, and become exposed in a valley, or on the side of a hill, the water may all be carried off as quickly as supplied, and produce therefore no permanent spring,—circumstances which render the search for water very precarious. It may be further added in respect to this example, that a rising or projecting spring can only be expected where the water passing between the detritus and the rock is pent up by them, and thus affords a head of water; as if it merely filters through, the pressure can only raise the spring to the height at which the water stands at the time in the reservoir or hollow. The other form of this case is, where the hollows of the crystalline rock are filled by stratified deposits (No. 20) of shale and

Fig. 20.



sand. Here, as the shale has been worn away, and the rock denuded at the summit, the water may gain access to the layer of sand (s^1), and produce therefore a spring under the bore-hole (*a*), the water being held back by the projection of

the rock to the left of it. When the water has saturated the whole of this stratum, it will rise over the projecting rock; but as the stratum is open to the valley below, it will be rapidly discharged, and produce no permanent spring under the bore-hole (*b*). Again, under both *a* and *b*, there will be a second supply of water due to the sand stratum (s^2); but as these lower reservoirs from their imperfect connection with the surface must require a considerable time to fill, their practical value will be in proportion to their magnitude, or to the quantity of water stored in them.

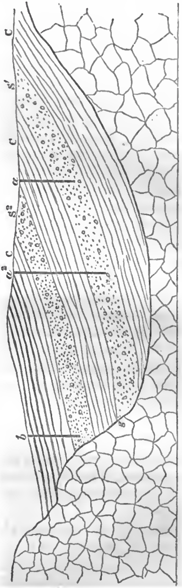


Fig. 21.

3. In the preceding instances, the accumulation of water has been considered to arise principally from that which flows over the underlying solid rock, but it may be entirely due to that which enters directly from the stratified deposits, and is merely held back or dammed up by that rock, as in No. 21.

Here it is evident that the supply of water will be in proportion to the extent of surface on which the rain falls, and from which it is directed to the layers of sand

(s^1 and s^2), the remaining mass being either clay or some other impervious stratum. If the supply be abundant, the stratum will be kept saturated up to the line of the bore-hole (a), and a constant spring be obtained; but if it be only small and casual, there may be a spring during the rainy season, or whilst the water is making its way through the stratum, but none at a later period, and the chance of permanency will be increased as the bore-hole is carried nearer to the rocky dam at g; and the same reasoning will apply to the upper stratum of sand (s^2), and its bore-hole (b): and it may be observed also, that a bore-hole (a^2) by which a temporary spring only had been found in s^2, by being carried through the intervening clays, would obtain a permanent one in s^1.

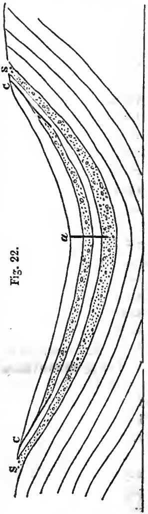


Fig. 22.

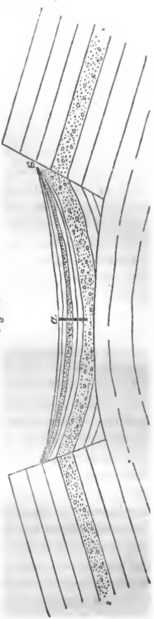
This case leads to those where the water is received and thrown up entirely by stratified deposits arranged in the form of basins or troughs, which may happen either where the basin is produced by an undulation or depression of the underlying strata, or where it occupies the valley produced by the disruption of these strata on elevation; and as some precaution is necessary in reference to this distinction, each case will be considered separately.

No. 22 is the first case where the strata of sand and clay have been deposited in a basin of undulation, and the water entering the sand stratum (s) is prevented from descending by the imper-

vious strata below, and from ascending by the clay above; so that it is pent up in the sand stratum itself. An inspection of the figure is sufficient to show that the nearer the bore-hole is made to the lower point of the valley, the more abundant and secure will be the supply, and the higher the jet from the aperture. If, instead of one layer of sand or gravel, there had been several, the reasoning would be the same, only it might happen that the upper layers, closed up by the clay passing over them, as in the figure, would be found unproductive of water, or that two layers of clay might come into contact with each other, and shut out the sand, cases which have been illustrated by recent borings at Portsmouth.

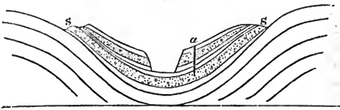
No. 23 is a basin formed within a valley of disruption or even of denudation, or which differs from the preceding only in this circumstance, that the boundary walls, as it were, of the valley may in themselves be partly pervious, and therefore allow the water to escape. If such occur, the water cannot rise above the level of these discharging strata, represented in the figure. And again,

Fig. 23.



secondary denudation may modify the basin deposit, and affect its supply of water, as in No. 24, where it is evident that any

Fig. 24.



layers of sand cut through by denudation in the centre of the basin must discharge the water they receive at once into the inner valley of denudation, and that no water can be expected until the lower layer, or at least the first layer not affected by the denudation, has been touched by the borer. Faults may also materially affect the arrangement of springs, as in some cases when filled by impervious matter they act as dams, and in others discharge the water,—so that in boring in the vicinity of a fault, care must be taken to ascertain its condition, and if it be supposed open, to place the bore-hole in the strata dipping *from it.*

It is conceived that these examples are sufficient to explain the application of principles to practice in every case, and to show the great necessity of studying the geological as well as the physical character of a country in which water is sought for. In granite, and in most crystalline rocks, a search for water must be very precarious, as it can only occur in or connected with fissures. In stratified deposits, not metamorphosed, the occurrence of alternating porous and impervious beds brings the principle into operation; and in proportion as the porous beds are looser in texture, as in tertiary and post-tertiary sands and gravel, and the arrangement assumes a basin-like form, will the chance of success increase, and a correct knowledge of the stratification at the outcropping of the strata must therefore be the surest guide. In boring, the strata passed through should be compared with

those visible on the surface, in order to judge what specific stratum has been arrived at or passed through. Should there be no basin-like deposits of looser materials, the pursuit of water in more solid strata must be equally guided by a knowledge of their geological and physical peculiarities; as, for example, in the chalk and even in the oolitic districts, where numerous fissures allow the water to descend, until it is stopped by either a less fractured bed or by some of the divisional clayey beds of such formations; and when once such bed or stratum has been discovered in any district, it becomes an index for the operations of the borer.

Although the several methods of boring cannot be here described in detail, it may be well briefly to notice the most remarkable.—1. The common one, in which an auger is used for soft soils, and chisels or jumpers for rocks. In this mode the boring tool is connected with the surface by jointed rods, fastened firmly together, and which must be frequently raised to clear the hole of the débris; so that in great depths the weight to be raised and the time lost in separating and refixing the joints become sources of great expense.—2. The Chinese mode, by percussion alone; the borer itself weighing about 180 ℔s., and being suspended by a cord, is alternately raised and allowed to fall, the débris either passing up through grooves in the sides of the tool and being then drawn up when accumulated on the head, or received into a separate cylinder with a valve opening from below upwards. This method is much more economical than the common, and has been used very extensively in Germany, though it is subject to two accidents requiring great precaution, viz. the great difficulty of drawing up a broken borer, and the danger, from the flexibility of the cord, of the bore-hole taking an oblique direction, and therefore requiring to be abandoned.—3. The system of Fauvelle, in which a hollow borer, either an auger or a jumper, is used, the cutting tool being of larger diameter than the hollow stem, so that an annular space is formed around the borer; and water being forced down this space by

a force-pump, ascends by the tube, bringing with it all the débris, or if forced down the tube, ascends in a similar manner by the annulus. As this arrangement renders it unnecessary to bring the boring tools which are constantly kept clear up to the surface, a vast saving of time and expense is effected. The cities of London, Paris, Vienna, and Mentz are on tertiary basins, and the first two are now supplied with the most wholesome portion of their water by Artesian wells; the borings in the London basin passing through the London clay, which only yields impure mineral springs, and finding water either in the sands of the plastic clay, or in the fissures of the upper surface of the chalk.

In tracing out the sequence of strata which have now been passed under review, it is scarcely necessary to say that the Geologist should have his hammer almost constantly in hand, and will find it often desirable to use some description of clinometer in unravelling the intricacies of stratification. It is unnecessary to describe the hammer, as geological hammers can now be readily procured, and the form itself should be varied to suit the nature of the rock; or to figure any complex clinometer, as the observer may attain his object by very simple contrivances, such as a small wooden quadrant with a plumb-bob and a common pocket compass,—minute precision being unnecessary.

CHAPTER VIII.

Concluding Remarks.

THOUGH it is hoped that the sketch given in the preceding pages of this most interesting Science will have made its leading principles familiar to the reader's mind, it may not be useless to recapitulate some of them, and to suggest that caution which is necessary both for their right perception and their correct application.

Sedimentary deposits must be studied in their mineral condition, in their organic fossils, and in the order of their stratification. The mineral condition is an indication of the physical circumstances which regulated the deposit and so affected vegetable and animal life as to produce a peculiar local flora and fauna; but the physical condition of the earth's surface and the circumstances connected with it having frequently varied in time and place, the mere mineral condition of a stratum is insufficient to determine the epoch of its deposition.

The organic fossils represent the flora and fauna of the epoch of deposition, but the laws of organic development are not sufficiently known to enable the Naturalist to assume from *purely organic* considerations that any one generic or specific form must have preceded every other, and hence the fossils alone are not sufficient to determine a geological epoch.

Order of stratification, as it embraces the examination both of the mineral and organic conditions of a deposit at its suc-

cessive stages, or, in other words, of the physical and organic relations of the successive periods of deposition, is the only sure guide to the first determination of geological epochs. In applying it to this purpose, however, care must be taken to avoid those sources of error which have been pointed out; or to study stratification in districts which have not been thrown into confusion by disturbing forces, as the contortions they produce often place, to all appearance, the newer strata below the older, and sometimes invert a whole series of deposits. The relative ages of geological epochs being once established by the study of undisturbed districts, a clue is obtained by which the confusion of contorted strata may be reduced to order.

The natural progression of organic beings in space and time as represented by their lateral and vertical extension in geological strata has been sometimes violently interrupted by an elevation or depression of the strata by which the physical conditions required by such organisms were suddenly changed; a fact well exemplified at the junction of *unconformable* formations: but this is not always the case, and in districts therefore which have not been disturbed at the interval between two successive formations, and in which the superior formation is *conformable* to the inferior, the interruption of organic progression is due either to a gradual alteration of physical condition as to depth, or to a change of climate, or to both combined. In the case of violently interrupted progression there will be an abrupt and marked change of zoological characters; in that of a gradual change of physical condition, an equally gradual change of zoological character; in the one a sudden alteration of formation, in the other a transition. In the present state of natural operations, a gradual alteration appears to be the ordinary rule, and abrupt alteration, the local exception; and the labours of some modern Geologists have tended to establish the same deduction for the former epochs of the Earth's History.

The conditions of the earth which favour the continued existence of any specific organic form are now different in various

parts of its surface; nor can it be supposed, *à priori*, that at any epoch these conditions were perfectly uniform over the whole surface. And further, in the gradual progress of the earth to a state fitted for the reception of organic beings, it is reasonable to believe that some portions must have become habitable before others, the progression taking place from the Poles to the Equator, which is rendered more probable by the greater development of the earlier fossiliferous formations in both high northern and southern latitudes. Where disturbances by elevation had begun to alter the physical conditions of the surface, and to modify the distribution of sea and land, the natural organic progression must have been interrupted; but wherever such violent actions had not co-operated with the gradual change of temperature, it is reasonable to infer that the lateral and vertical extension of many organic bodies may have brought them into new positions on the earth's surface long after the conditions necessary for their continued existence had ceased at the original centre of their creation, and thus the characteristic organisms of one formation may appear at the epoch of another: but a mixture of characteristic forms of the new with those of the old formation will be usually found to explain the true state of this case. It is not therefore surprising that a carboniferous flora should appear in the Silurian, the Devonian, the carboniferous, and even more recent formations, although there can be little doubt that in each case careful observation will discover the new organic types which characterize the change of epoch.

This difficulty of always determining the actual simultaneity of apparently similar formations in no respect affects the practical application of Geology. In limited countries, such as Great Britain and Ireland, the physical conditions cannot have varied so unequally as materially to protract the existence of organisms in one place more than another; and hence the order of geological formation being once well established in one district, it becomes a certain guide to the examination of any other. In more enlarged spaces, though synchronism of

formation may not be established, the organic group which in one country co-exists with some definite product being discovered in another, it may be assumed as at least probable that the associated product will also be discovered.

Vast masses of strata which were once apparently stratified deposits have been so metamorphosed or changed that their original structure can no longer be recognized. Experiments in the laboratory have proved that similar changes can be effected on the small scale; and it is reasonable to conclude that the long-continued and intense heat of the earth acting under pressure upon stratified deposits was sufficient to reduce them to the condition of the crystalline schists.

Rocks which had been in a state of igneous fusion can be traced from the earliest epochs, and they are found to graduate into the true volcanic rocks of the present time. The effects they have produced on some of the strata frequently determine the epoch of their appearance, but there is often much difficulty in determining the relative ages of such rocks, and still more the depths from which they have proceeded. It has been here suggested that specific gravity may possibly afford the safest method of solving such questions, and in conformity with such rule, that granite has probably proceeded from a less depth than most of the porphyries and basalts.

The penetration of strata, in the form of dykes, by igneous rocks, the contortions of the strata, and the elevation of mountain chains, are so many proofs of the operation at various epochs of disturbing forces, the results of which are still observed in volcanoes and earthquakes. If the primary cause of such disturbances be the pressure of the solidifying and contracting crust upon the still liquid nucleus of the earth, it is reasonable to believe that the inteusity of the elevating force should increase with the augmenting thickness and pressure of the contracting crust, though the quantity of matter erupted may decrease; nor is this inconsistent with facts, as some of the greatest mountain chains have been elevated at comparatively recent epochs, whilst the ancient basaltic flows

appear to have been, as a whole, more extensive than those of recent volcanoes. In respect to contortions, they may be either explained as the result of pressure on the solidifying strata by the wave-like movement of the disturbed fluid matter, or be considered, according to the theory of Professor Rogers, to represent the wave itself continued into the crust. To Professor Rogers is due the most laborious and accurate examination of the facts of contortions, and a most perspicuous enunciation of his theory founded upon them, but it is very doubtful whether any simple wave of translation of a dense liquid mass can be made to conform to the varied forms of contortion. Whilst, then, such swells of the comparatively level surface, as have been demonstrated by the pendulum deductions of M. Rozet may be reasonably considered waves conforming to those of the liquid nucleus, contortions are more probably the effect of pressure on strata, which not being sufficiently elastic either to follow the movement of the liquid wave, or to transmit the vibration or quake of a solid medium, are folded together.

In studying many natural phenomena, such for example as denudation, the apparent magnitude of a result should not be allowed to oppress or perplex the mind, as it must be remembered, that though almost immeasurably vast in the limited perceptions of man, they are atomic when compared to the magnitude of the earth itself; but this is not the case as regards the estimation of forces in the explanation either of wear or of contortions, as the laws of matter are uniform and general, and the force of gravity may be studied as well in the fall of a pebble as in that of a mountain, or the magnetic force of the earth estimated by the vibrations of a needle. The phenomena stand forth as facts to be observed and studied; but in seeking to explain them, no supposition of unknown forces, immense in proportion to the forces we see acting on the earth as the earth itself is to the mountain which studs or the valley which dimples its surface, can be admitted. The density of the earth, and the laws which regulate its motion, are known,

and the general properties of matter, whether at rest or in motion, are also known; and it cannot therefore be said that the elements are wanting for the full elucidation of all physical phenomena, or that any theory is fully established which cannot be shown to conform to known physical laws.

THE END.

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